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SPACE LAUNCH VEHICLE

FULL-SCALE DAMPING TESTS

GDA63-0376

21 JUNE 1963

Contract AF 04(694)-185

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GENERAL DYNAMICS | ASTRONAUTICS
A DIVISION OF GENERAL DYNAMICS CORPORATION

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SUMMARY

The wind study portion of testing showed that the SLV gantry tower is sufficiently stable to be used as a base for forced oscillation of the vehicle and that any measurement of relative motion between the vehicle and tower is of vehicle movement only.

The structural damping ratio of the first cantilever mode of Atlas Agena 461 and 698 BJ varied between a high of 2.14 percent and a low of 0.57 percent, depending upon the axes and the tanking condition. It was not possible to determine a damping factor for all cases by the methods used because of the internal (liquid) movements, but for many conditions damping factors were determined with good accuracy.

In general the theoretical frequencies were verified to an excellent degree. The experimental damping factors agreed reasonably well with the results of previous tests. Increased confidence in the recent SLV ground wind restrictions has been the direct result of this test.

Table 1 presents a summary of the results of the tests run on Vehicle 149D.

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SECTION 1

INTRODUCTION

Recent wind tunnel tests of a SLV 1/15-scale model, required because of a lack of test information concerning or an analytical means of determining wind-induced vehicle oscillations, have resulted in severe ground wind restrictions on SLV launches. Upon investigation of the model test results and their conversion to full-scale data, it was found that damping factors were assumed equal to the damping factors determined in other than Atlas Agena tests, and would require clarification before complete confidence was placed in the new restrictions. This clarification took the form of the subject full-scale damping test.

Damping factors comprise the overall effect of innumerable small friction forces that tend to resist deformation of the vehicle. These small forces include all the different kinds of friction (coulomb, viscous, mechanical, hysteresis, etc.) that occur in and between various parts of the vehicle. The importance of each of these friction forces in a given tanking condition depends upon the relative amount of deformation in or between various parts. It follows, then, that different tanking conditions may have different damping factors and that if the mode shape is altered by a change in payload configuration, the corresponding damping factor may be changed.

SECTION 2

DESCRIPTION OF TESTS

2.1 TEST SPECIMENS. The test specimens were the Atlas 119D and Atlas 149D in flight condition, a partially stripped Agena B, and two dummy payloads with fairings, one with the mass and elasticity of the 461 payload and the other with 698 BJ. For the 698 BJ configuration, the Agena was modified in that the instrument rack was lengthened to that used for flight. The standard handling yokes and protective covers were not removed from the Agena. Weights were attached to the handling yokes to simulate the mass and cg of those items which had been removed.

The Atlas-Agena configuration was erected on the Pad 2 launcher, and the Agena umbilical tower was raised. All wind screens on the tower were closed and the umbilical tower sails were extended.

Tests were performed with various combinations of Atlas and Agena fuel and oxidizer tanking conditions. Throughout this report, tanking conditions will be expressed as Atlas tanking conditions first and Agena second. Atlas condition fueled means the fuel tanks are full and oxidizer tanks are empty. Condition full means fuel and oxidizer tanks are full.

Water was substituted for the Agena fuel and methylene chloride for the oxidizer. Additional weights were attached to the yokes to simulate the weight and cg of the actual fuel and oxidizer.

The Atlas was fueled with RP-1, but liquid nitrogen was substituted for liquid oxygen in the oxidizer tank. No weight or cg corrections were made for this substitution.

2.2 TEST METHOD. The vehicle was oscillated at its natural first mode frequency and then disconnected from the excitation mechanism. The rate at which the free oscillation decayed was a function only of the damping except to the extent that wind or fuel slosh disturbed the system.

2.3 EXCITATION MECHANISM. Excitation was accomplished by a hydraulic cylinder with a feedback transducer and servovalve. Varying frequency sinusoidal motion was secured by driving the hydraulic servovalve with a variable frequency electrical oscillator. Since the damping was obtained by measuring the rate of free decay missile oscillations, it was necessary to be able to disconnect the shaker from the vehicle. This was accomplished by a small hydraulic cylinder which would open or close a clamp. This clamp mechanism, its operating cylinder, and an oscillation cylinder were mounted on a single base easily moved by two men. This shaker unit was bolted to one of two built-up I-beam frames to secure oscillation in either the

X or Y axis. Each of the frames was bolted through the gantry tower floor directly to the tower to secure a stable platform.

Included in the force transmission system of the shaker was a load cell; the output of this cell was the source of the maximum load redline.

The special yokes which can be seen on Page C-5 were bolted to the 502 ring with 30 bolts to distribute the load. They were flexible in all directions except horizontal to ensure that they did not twist the vehicle. The X-axis displacement was measured on the Y-axis adapter and the Y displacement on the X-axis adapter with motion transducers.

2.4 **INSTRUMENTATION**. The vehicle instrumentation as recorded on the main Sanborn recorder consisted of an X-axis position transducer, Y-axis position transducer, X-axis strain gages (regular and standby), and Y-axis strain gages (regular and standby). The output from the load cell and the position feedback from the transducer were also recorded on this instrument.

The X-axis and Y-axis rate gyros and Z-position transducer were recorded on a separate Sanborn recorder. The wind velocity as measured on the blockhouse anemometer was recorded on a Honeywell Visacorder. The time of day as generated by the Pacific Missile Range Clock (see Reference 1) was included on each recorder so that the results could be compared.

2.5 CALIBRATION OF TRANSDUCERS AND RECORDERS

2.5.1 Position Transducers. The position transducers were calibrated by placing test blocks between the end of the transducer and the yoke. Sanborn recorder channels were calibrated so that full pen deflection equaled ±1/4 inch in transducer deflection.

2.5.2 Load Cells. The load cell was calibrated using a dead weight system. The Sanborn recorder channel was calibrated so that full-scale pen deflection equaled ±400 pounds on the load cell. This measured loading was accomplished by placing the load cell in a mechanical screw system, so that the tensile and compressive force could be applied to the yoke.

2.5.3 Strain Gages. Strain gage recording channels were calibrated so that full-scale pen deflection was ±400 pounds static load at the 502 ring. Deflection of the position transducers was also recorded at this time.

2.5.4 Rate Gyros. The rate gyro recorder channels were calibrated by applying calibration signals and comparing pen deflection to factory calibration charts.

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2.6 <u>WIND STUDY</u>. The motion of the Gantry Tower was observed through a transit for a period of several days. It was observed that very little motion occurred even though the wind was quite strong. This small tower sway measurement eliminated the possibility that the position transducers could not be used to measure the decay of missile oscillations.

2.7 <u>DAMPING TEST CONFIGURATIONS</u>. The damping test on missile 149D was divided into a test of both the 461 and 698 BJ configurations. Each configuration was tested in the X and Y axes for six different tanking conditions. The Atlas-empty/ Agena-empty condition was tested with umbilical connected and disconnected in order to determine the effect of the umbilicals upon missile damping. In addition to the test on Atlas 149D, the following testing was made on Atlas 119D in a 461 configuration.

<u>RUN NUMBERS</u>	<u>ATLAS</u>	<u>AGENA</u>
1 through 4	Empty	Empty without umbilical
5 through 8	Empty	Empty without umbilical
9 through 12	Empty	1/2 Full
14 through 26	Empty	Full
27 through 28	Fueled	Full

The tests on 119D were discontinued because the pad was scheduled for a launch.

2.8 <u>BENDING MOMENT MEASUREMENTS</u>. Strain gages were installed and their output recorded in an attempt to determine actual bending moments and as a backup system for the position transducers. These strain gages operated satisfactorily until the Atlas was fueled. Then the hoop stress caused a deformation many times greater than that caused by the oscillatory bending moments.

2.9 <u>REDLINES AND SAFETY FEATURES</u>. The Atlas vehicles used for these tests were scheduled for flight. Therefore multisystems of redline values were established to ensure the safety of the Atlas.

2.9.1 <u>Load Cell System</u>. A load cell was always used to measure the force applied to the vehicle. A maximum unidirectional force of ±400 pounds as specified in GD/A memo 663-4-62-017 was the established redline for this system. During the test the dynamics engineer held the disconnect switch in his hand and watched the Sanborn recorder trace of the load cell output, and was prepared to disconnect if the load on the vehicle exceeded specifications.

2.9.2 Position Redline. When calibrating the strain gages the deflection at the 502 ring for ±400 pounds of loading was recorded and approximately 80 percent of this ratio was established as a deflection redline. This redline was used by the test conductor as the limiting value of deflection so that when forced oscillations reached a redline value, the command "disconnect" was given.

2.9.3 Rate Gyros. Since with frequency and mode shape known the rate gyros' output is proportional to deflection, they were used as an independent redline system to assure that the missile was not overloaded. The deflection redlines as discussed above were established as 0.45-inch peak-to-peak deflection for the Y axis and 0.35-inch peak-to-peak deflection for the X axis. On a frequency of oscillation versus gyro output curve for the vehicle rate gyros, these deflections will appear as straight lines (see Figure 1).

Before starting forced oscillation, the forcing frequency was announced to the rate gyro monitor, who with the aid of (Figure 1) would calculate a redline for that run. Throughout the test he would monitor the Sanborn trace of the rate gyro output and notify the test conductor if the gyro indicated excessive deflection.

2.9.4 Mechanical Block. In order to protect the vehicle against human or electrical failure, a travel limit was placed in the forcing cylinder. This consisted of two sets of steel blocks, which when placed inside the cylinder limited the piston travel to 0.35 inch or 0.45 inch as required for the X and Y axes, respectively.
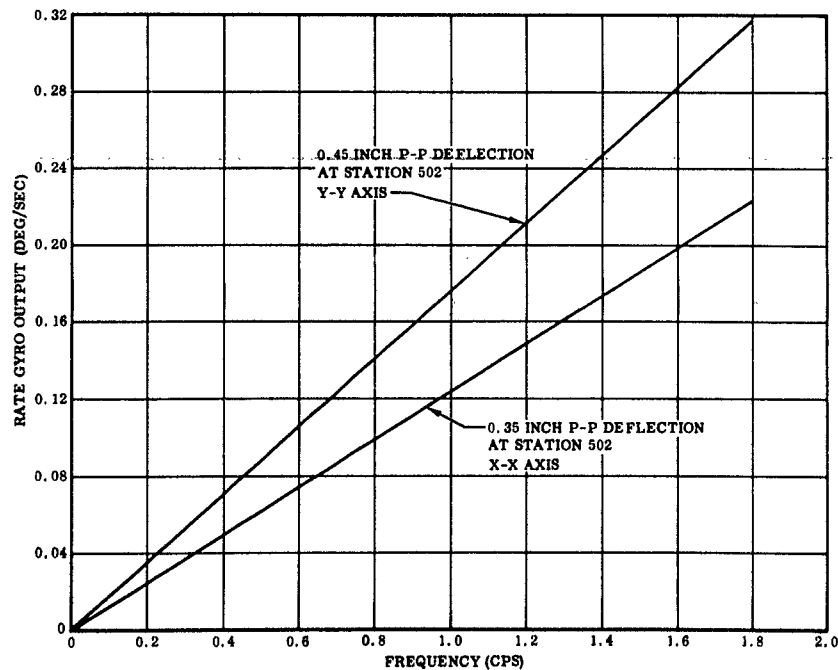
Figure 1. Rate Gyro Limits Versus Frequency

SECTION 3

DATA REDUCTION

The reduced data published in this report was obtained by directly measuring deflections on the Sanborn recorders. Frequencies were obtained by counting the number of cycles per unit of time; time was recorded on the same record from the range clock.

The technique employed to obtain the damping ratio consisted of measuring the peak-to-peak amplitude of the position transducers at each cycle of the transient decay. This amplitude was plotted against the number of cycles of decay on semilogarithmic graph paper. Several runs were superimposed on a single sheet, care being taken to superimpose at equal amplitudes. It was usually possible to find a smooth curve that represents these points. The slope of the line tangent to the curve, is related to the ratio of critical dampings at that amplitude. The damping ratio was then determined from a simple overlay made for this analysis.

The overlay was based on the damping ratio equation: $G = \dfrac{1}{2\pi n} \ln \dfrac{x_o}{x_n}$

Where x_o = amplitude at start of measurement

x_n = amplitude at n^{th} cycle

n = number of cycles

On semilog paper, this can be graphed as a number of lines, all originating at some amplitude x_o and radiating outward to various cycles at amplitude x_n; the slope of each line was related to the damping ratio as calculated by the formula. The error inherent to this technique is much less than that due to reading the recorded data or in reading the records themselves.

The calculated damping factors presented in Table 1 were substantiated by the data acquired in the test of Missile 119D.

Superimposing the data of the tests of missile 119D on the data included in this report would have made no difference in the damping factor. Also the results of the test on 119D were not used because better weather conditions and improvement in technique resulted in less scattering of results on missile 149D.

Table 1. Test Result Summary
(Vehicle 149D)

ATLAS TANK CONDITION	AGENA TANKS CONDITION	MISSILE AXIS	RUN NUMBERS	MEASURED FIRST MODE FREQ CPS	CALCULATED DAMPING FACTOR	PAGE NO. OF CALCULATION	
Empty	Empty without umbilical	X	30 thru 34	1.64	0.82	B-2	
Empty	Empty with umbilical	X	35 thru 39	1.62	1.06	B-2	
Empty	1/2 Full	X	40 thru 50	1.08	2.05	B-2	461 CONFIGURATION
Empty	Full	X	51 thru 59	0.77	0.60	B-2	
Fueled	Full	X	60 thru 65	0.77	0.57	B-2	
Full	Full	X	66 thru 73	0.57	0.90	B-3	
Empty	Empty without umbilical	Y	104 thru 109	1.48	1.30	B-3	
Empty	Empty with umbilical	Y	99 thru 103	1.46	1.66	B-3	
Empty	1/2 Full	Y	93 thru 98	1.00	2.14	B-3	
Empty	Full	Y	74 thru 83	0.72	1.42	B-3	
Fueled	Full	Y	84 thru 87	--	Beating	---	
Full	Full	Y	88 thru 92	0.52	0.79	B-3	
Empty	Empty without umbilical	X	185 thru 188	1.17	0.78	B-4	
Empty	Empty with umbilical	X	181 thru 184	1.17	1.00	B-4	
Empty	1/2 Full	X	176 thru 180	0.91	0.88	B-4	698 BJ CONFIGURATION
Empty	Full	X	170 thru 175	0.71	0.63	B-4	
Fueled	Full	X	157 thru 160	--	Beating	---	
Full	Full	X	161 thru 166	0.56	0.78	B-4	
Empty	Empty without umbilical	Y	110 thru 115	1.10	1.32	B-4	
Empty	Empty with umbilical	Y	116 thru 121	1.09	1.38	B-5	
Empty	1/2 Full	Y	122 thru 126	0.86	1.35	B-5	
Empty	Full	Y	127 thru 141	0.66	1.25	B-5	
Fueled	Full	Y	142 thru 150	0.66	0.91	B-5	
Full	Full	Y	151 thru 156	0.50	0.85	B-5	

SECTION 4

DISCUSSION

It was observed that in all but two cases the damping ratio reduced with amplitude. This was the expected result for it is believed that when amplitude becomes very low, friction between built-up sections becomes negligible and the total damping will become lower. The two unusual cases have not yet been satisfactorily explained, but it is believed that as amplitude further decreases these cases will also have a lower damping ratio.

It is reasonable to assume that as the amplitude of the oscillation exceeds the redlines used in this test (this will occur well below the limiting stress level), the damping ratio will continue to increase, thus making the calculated limiting ground winds conservative.

A position transducer was installed to measure how much the 502 ring was lowered due to settling of launcher, thermal contraction, and the increased diameter of the tanks when loaded with fuel and LN_2. This lowering was measured as approximately 1/4 inch, which agreed with calculated prediction. It was also observed that the vehicle leaned when the liquid nitrogen was in the oxidizer tank. Possible causes may have been temperature-induced shortening of the external oxidizer line and/or vehicle misalignments causing load eccentricities.

In the empty/full and fueled/full case, the motion of the fluids inside the vehicle caused considerable scattering of data points. In two fueled/full cases the natural frequency of the fuel sloshing and the vehicle were so close that beating occurred. The calculated damping ratio for these conditions is probably lower than the effective damping resisting the building up of oscillations.

SECTION 5

RECOMMENDATIONS FOR FUTURE BENDING TESTS

In future tests of this nature, it is recommended that the use of a constant force exciter be studied. With a variable-frequency constant force exciter, the frequency could be tuned to maximum displacement and the damping factor calculated from this amplitude. Thus the damping factor could be determined at tanking conditions which beat under decaying conditions.

If a similar hydraulic shaker is contemplated, it is recommended that the electric controls be so constructed that there is no shift in the zero position of the oscillation with a change of amplitude.

It would be desirable to be able to determine the steady state and oscillatory bending moment in the vehicle in all tanking conditions. It may be possible to accomplish this by instrumenting the launcher. It is recommended not to depend only upon strain gages on the skin of the Atlas.

SECTION 6

REFERENCES

1   F. Yawes, Operation and Maintenance Handbook Landline Instrumentation
    System PALC 1,   AP62-0058, 1 May 1962.

2   R. A. Mallgren, Test Plan Full Scale Damping Determination at PALC 1,
    AE62-0744, 10 August 1962.

3   Memo 663-4-62-017, Revision B, Full Scale Damping Test Safety Margin,
    7 November 1962.

4   Parameter Study of Atlas Bending Modes, AE60-0230, 15 September 1960
    (Confidential).

5   Full Scale Damping Determination and Wind Study Test, Evaluation Test
    Report No. 69A-2657, 11 June 1963.

APPENDIX A

PLOTS OF INDIVIDUAL DAMPING RUNS
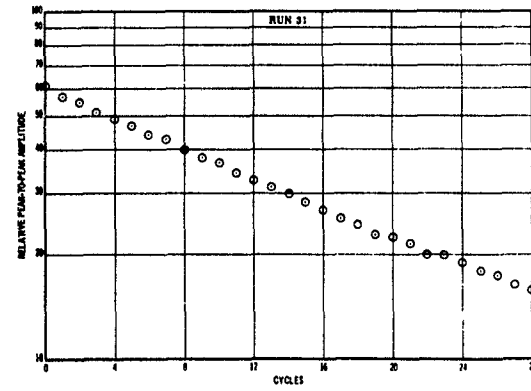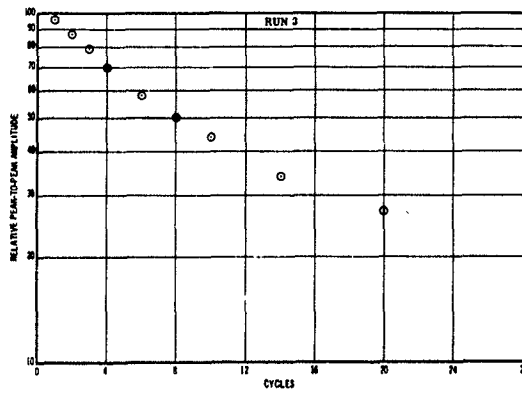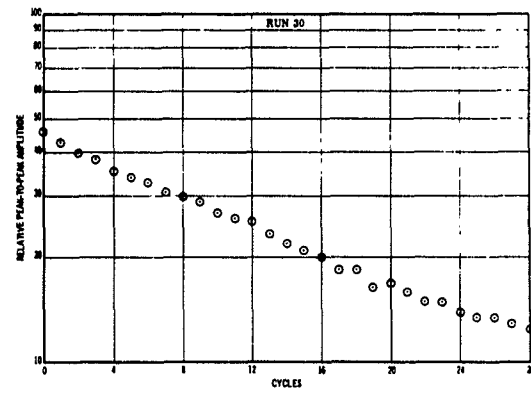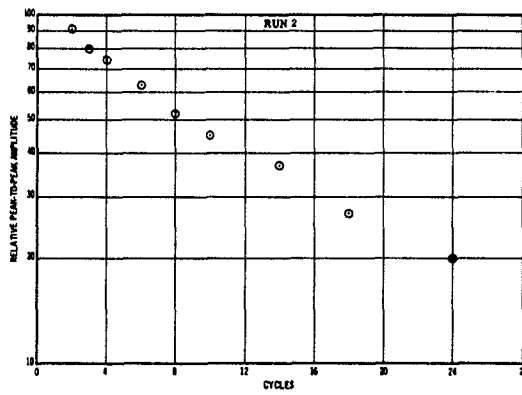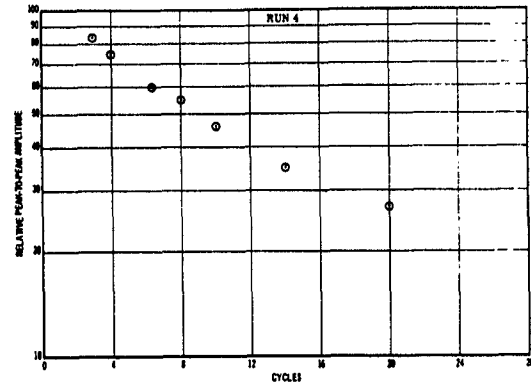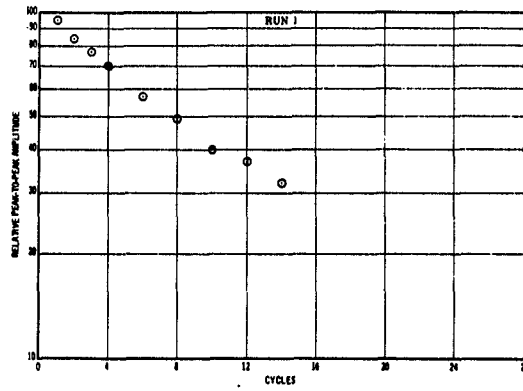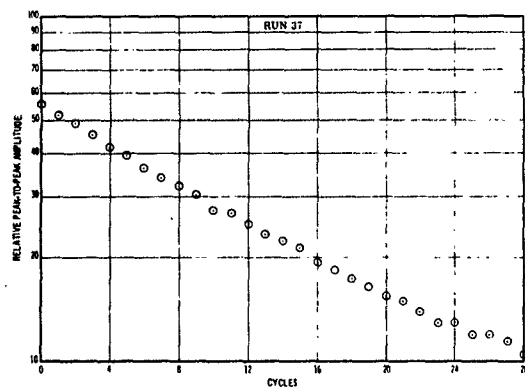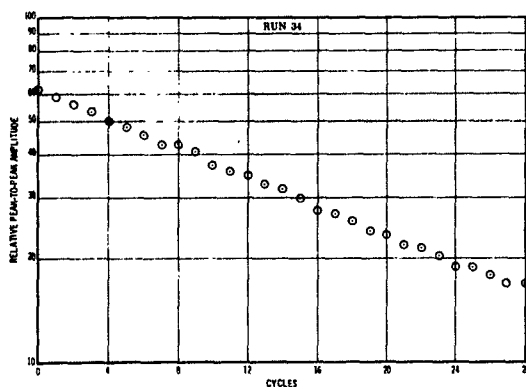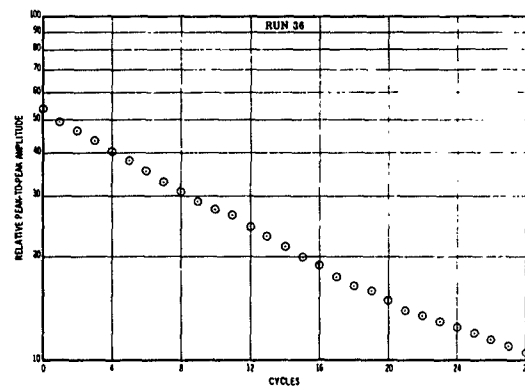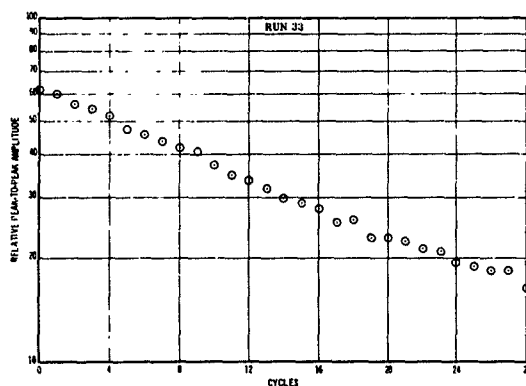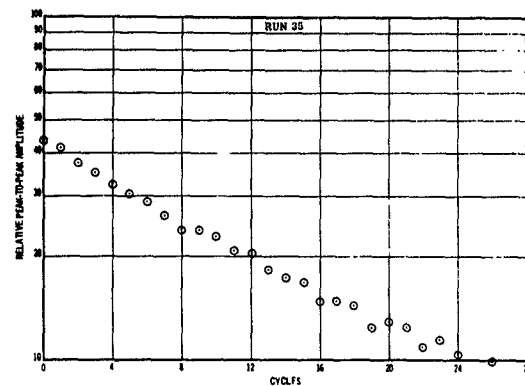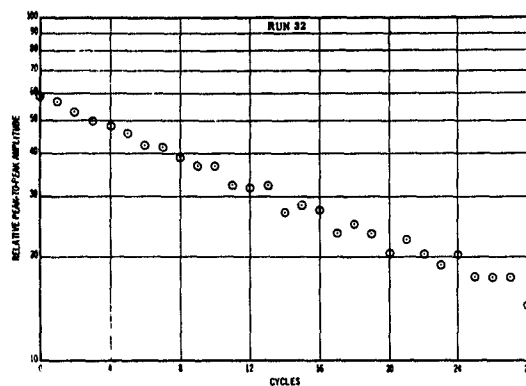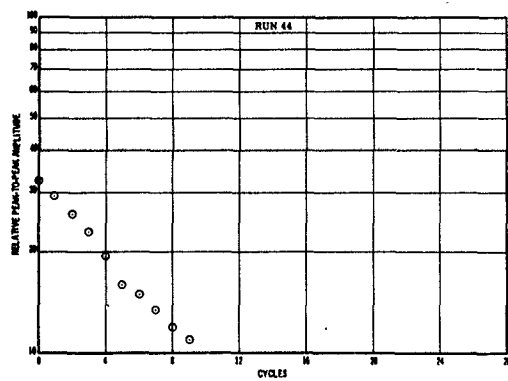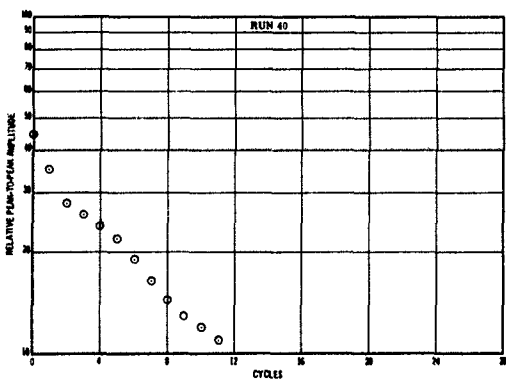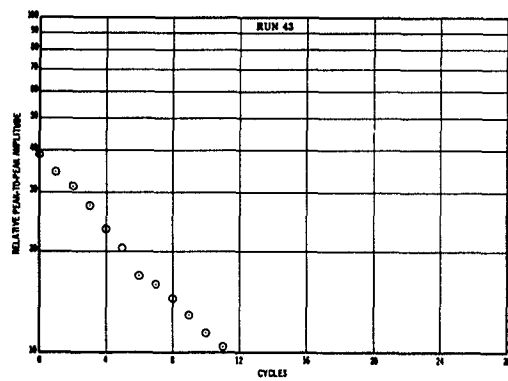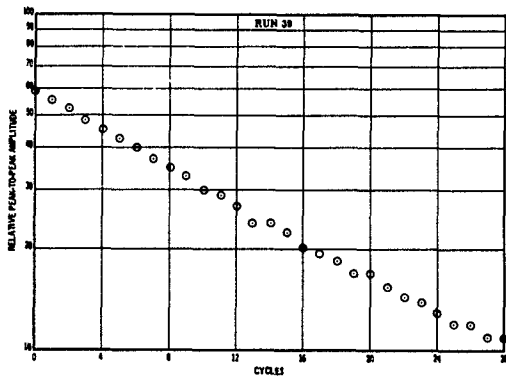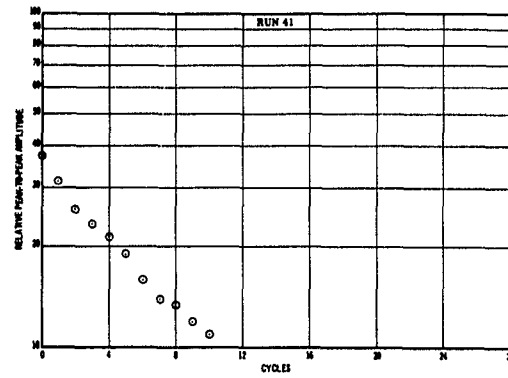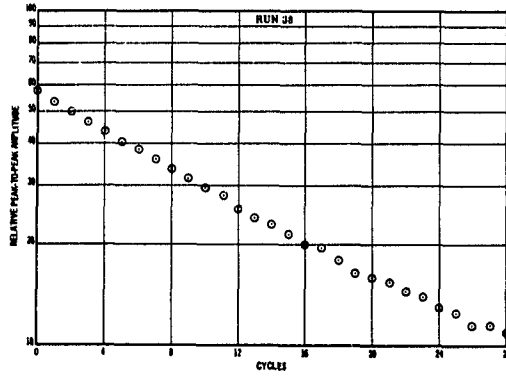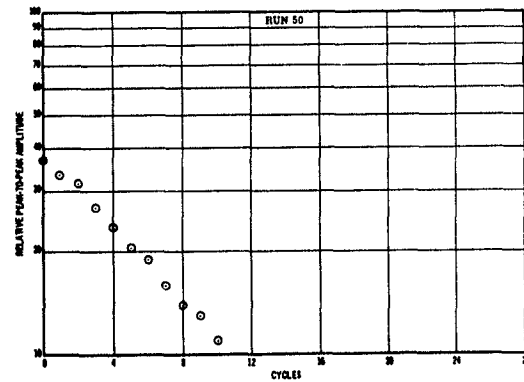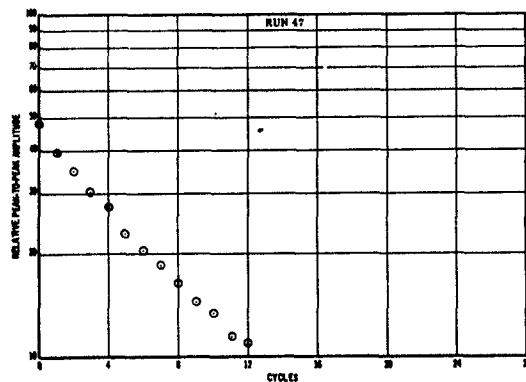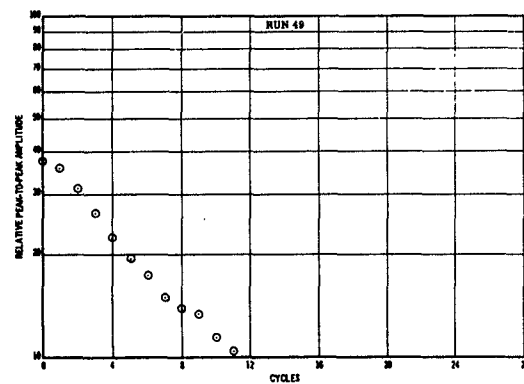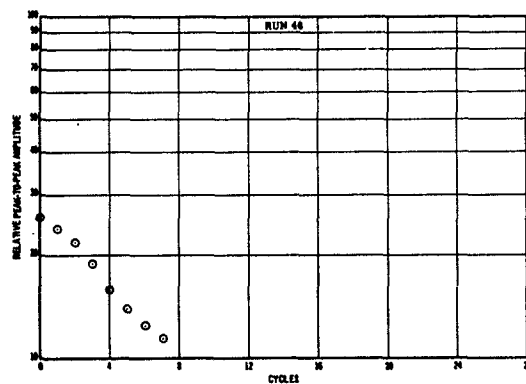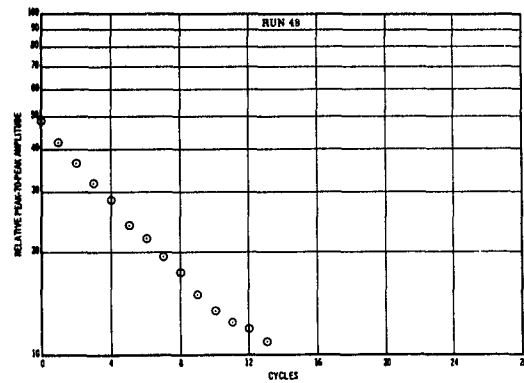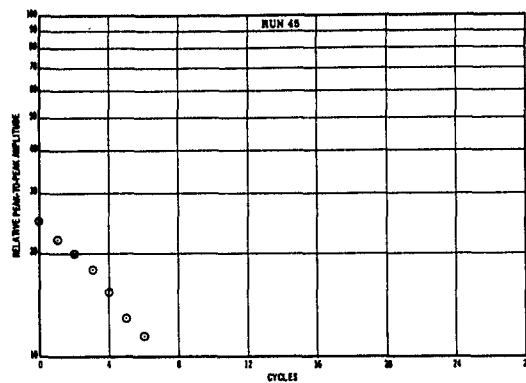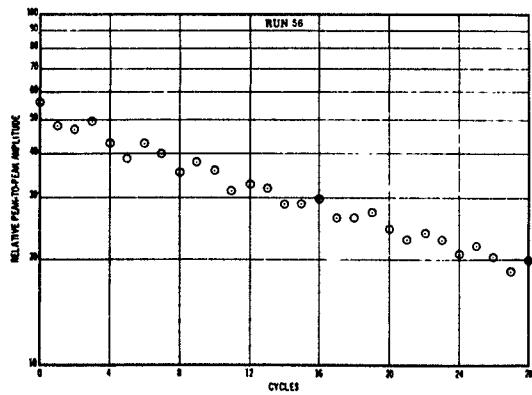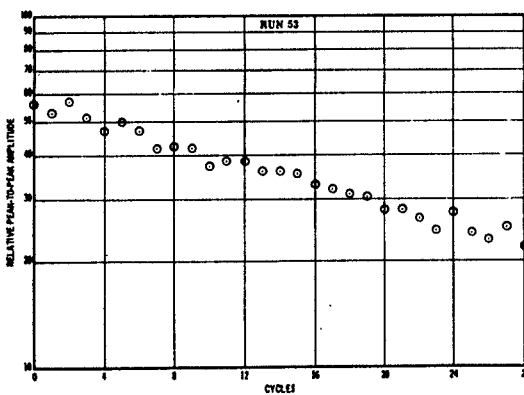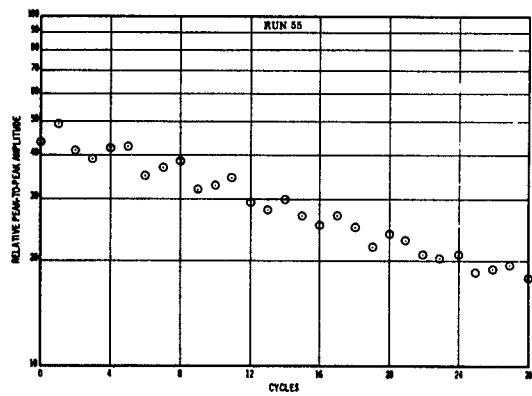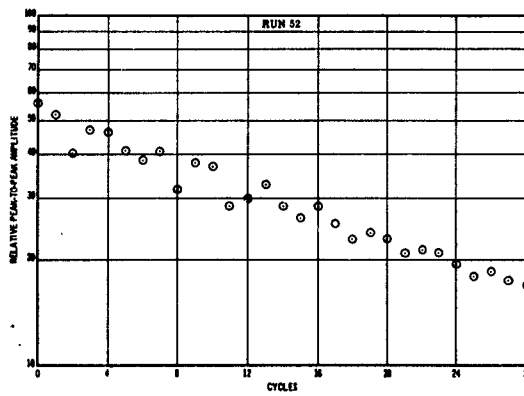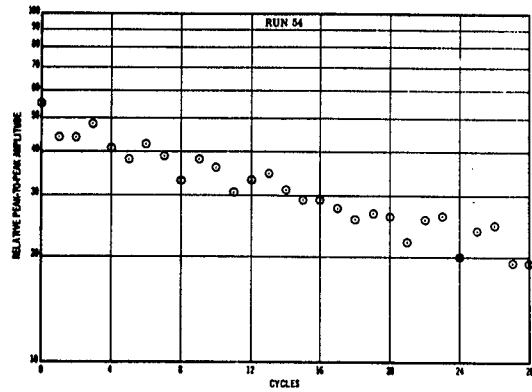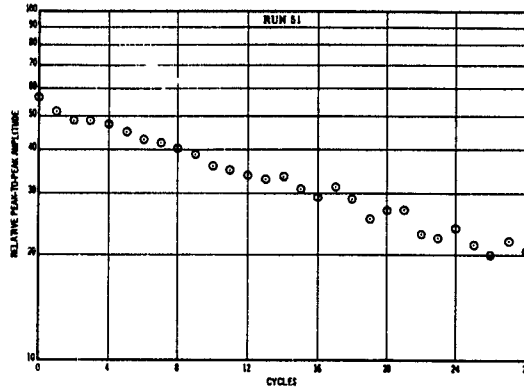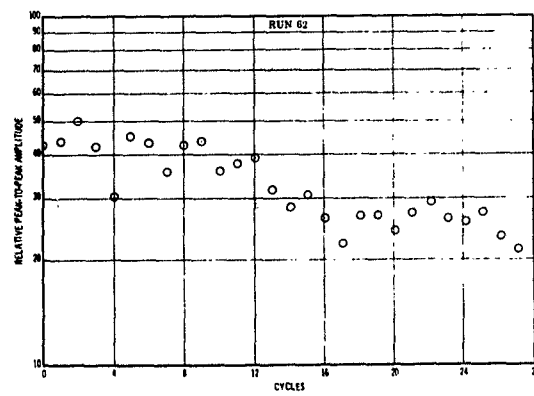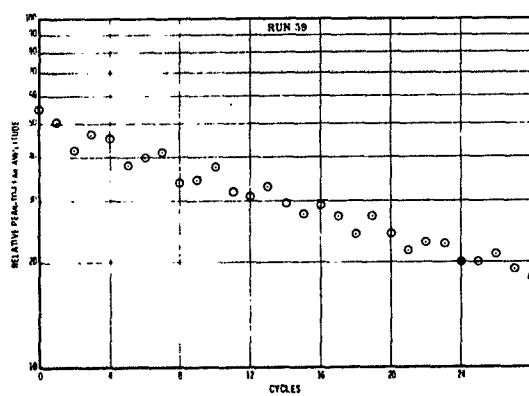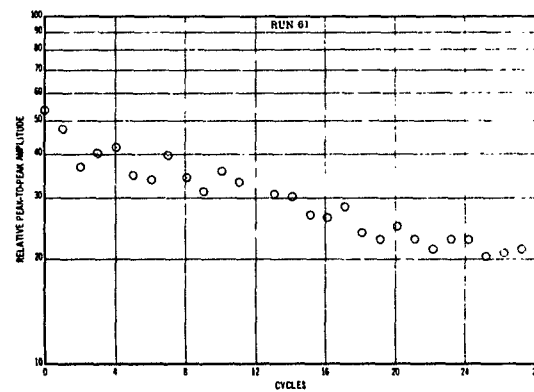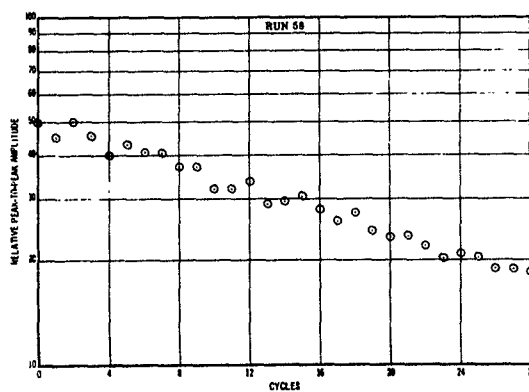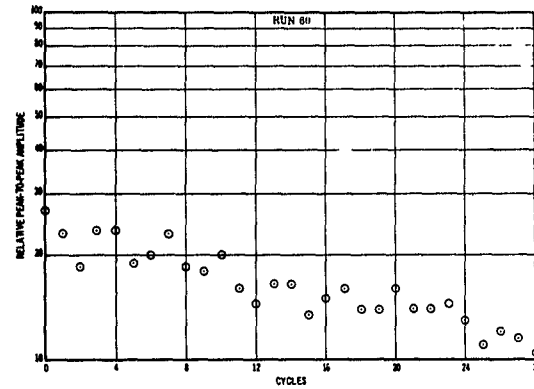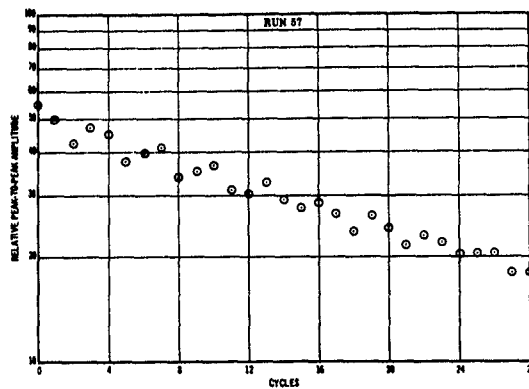
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RUN 121

RUN 119

RUN 122

RUN 120
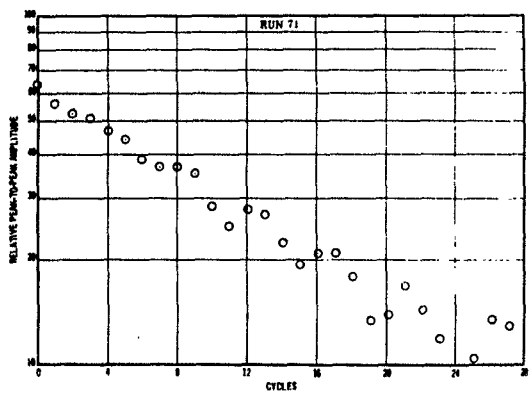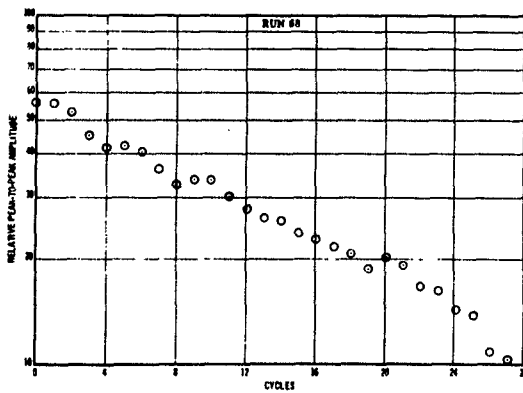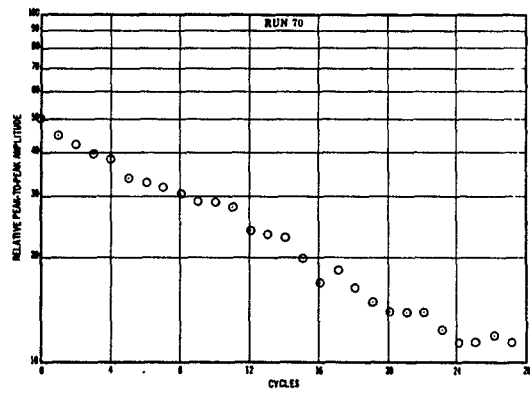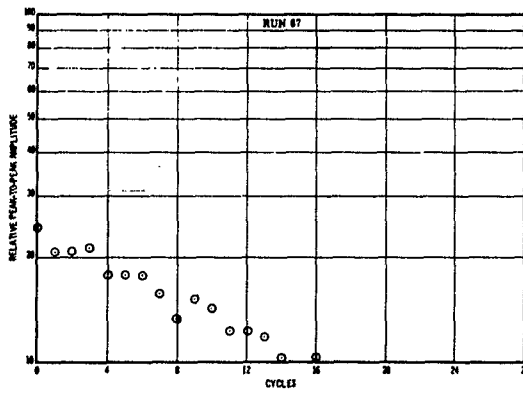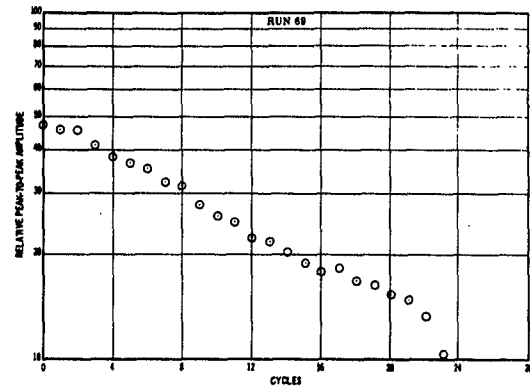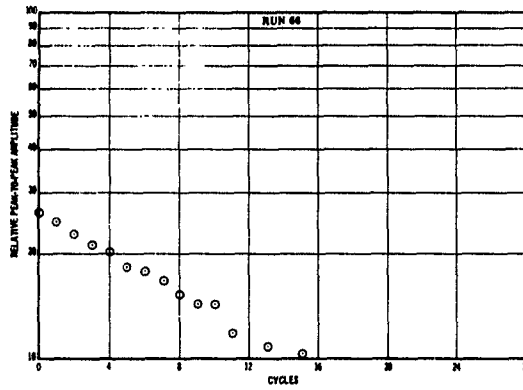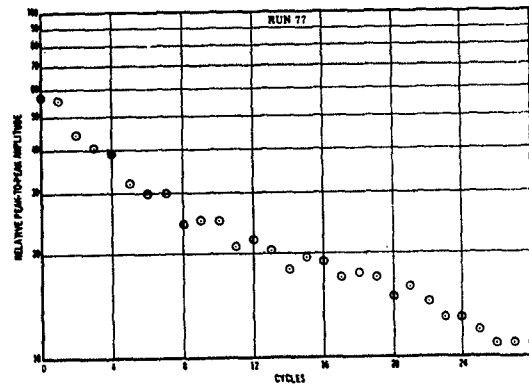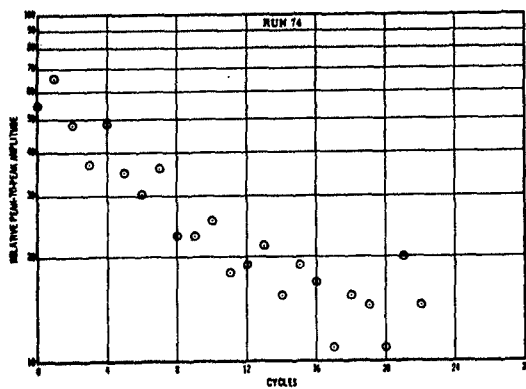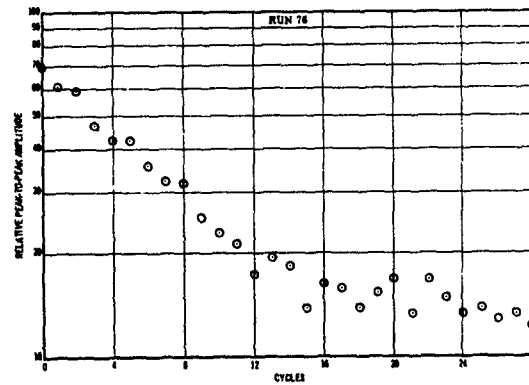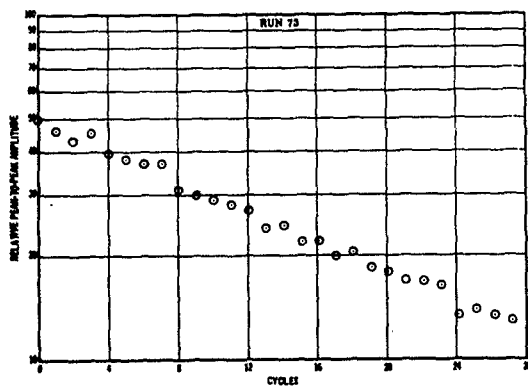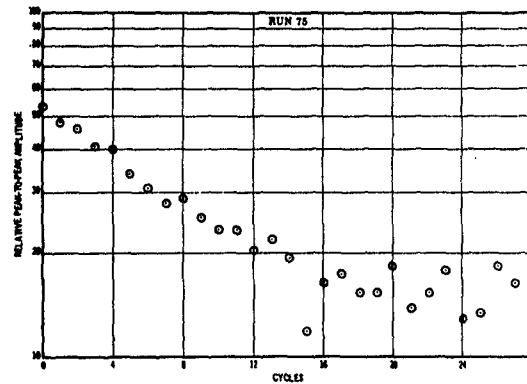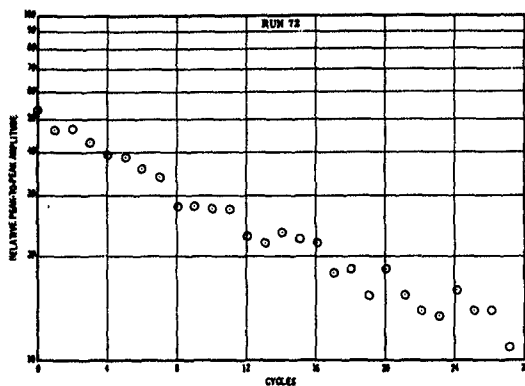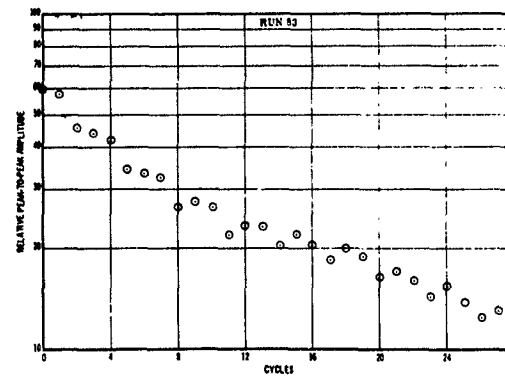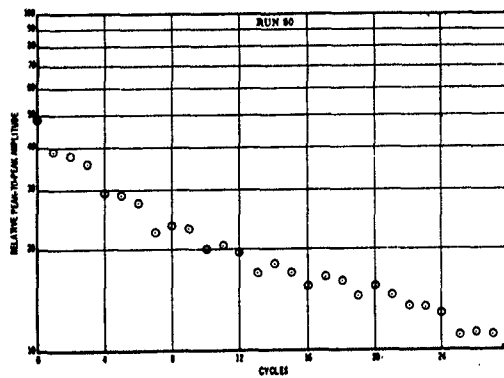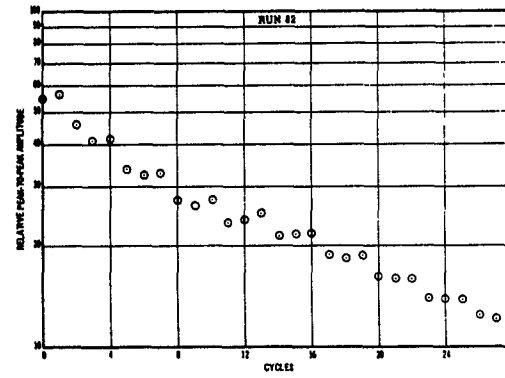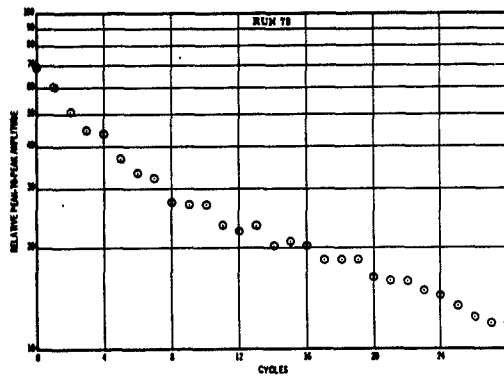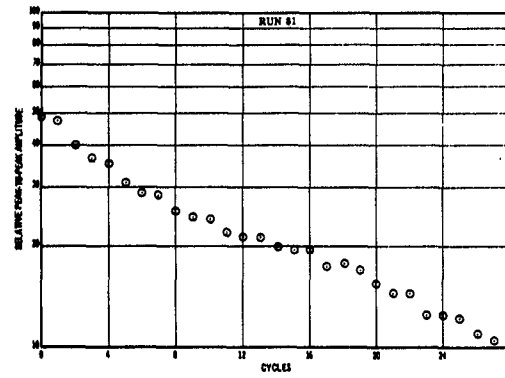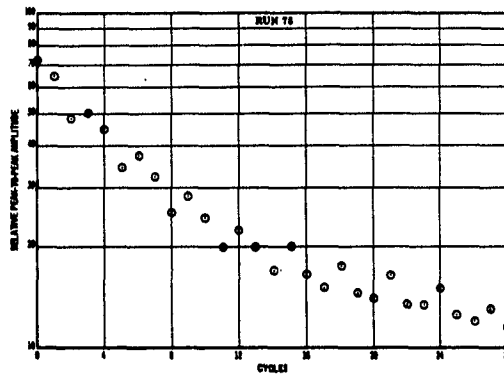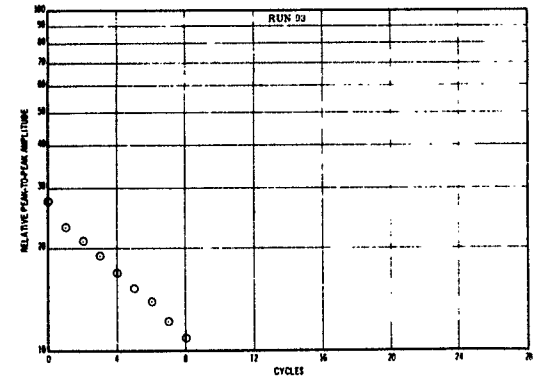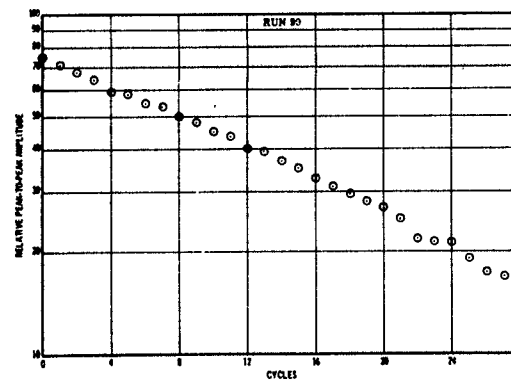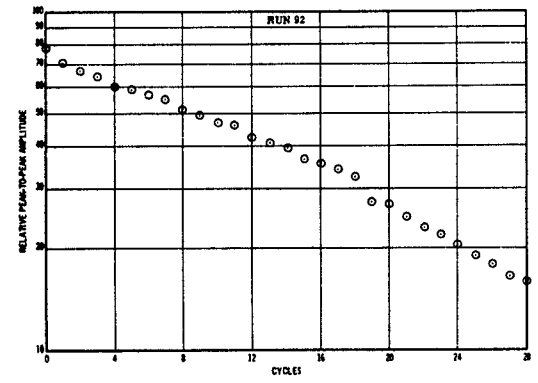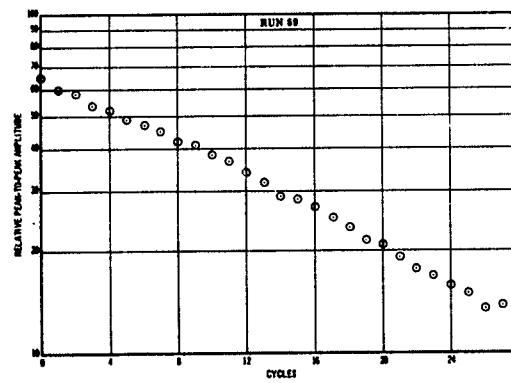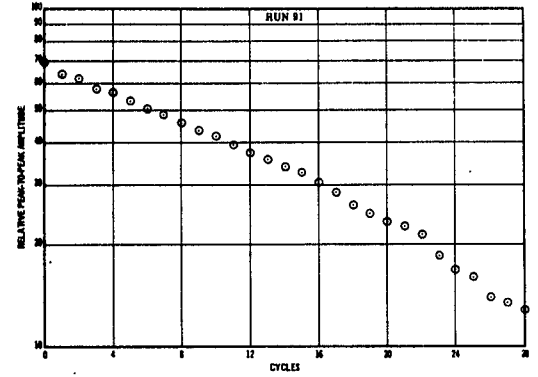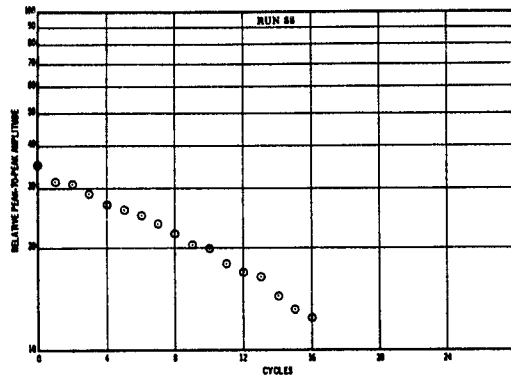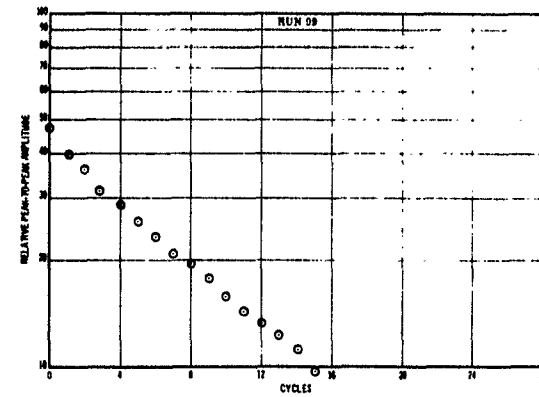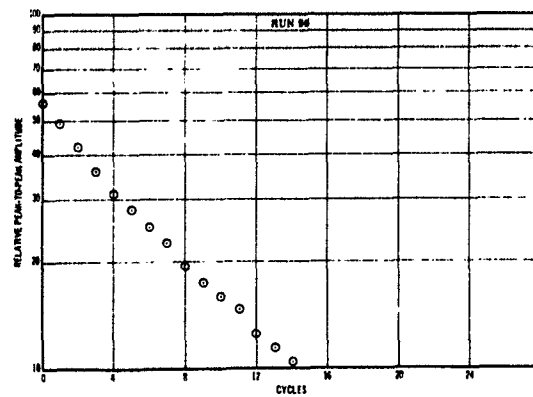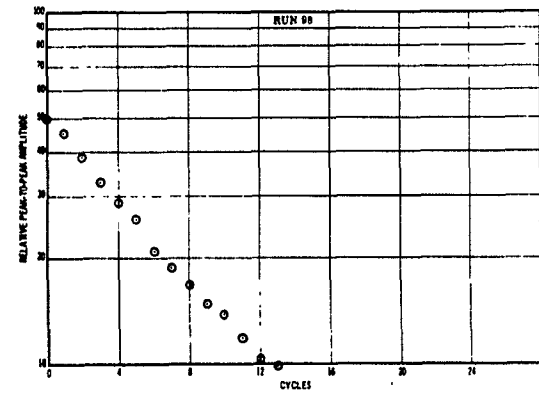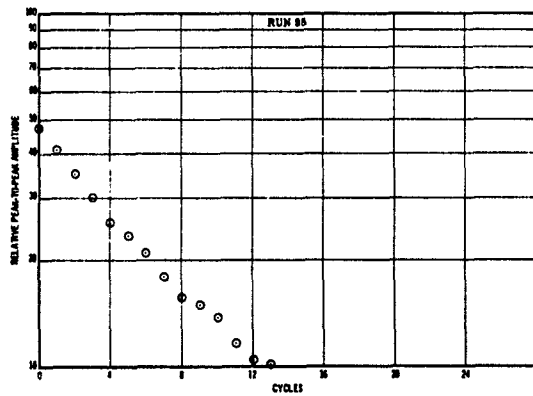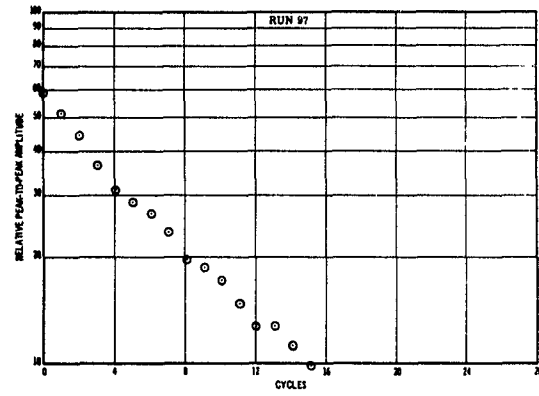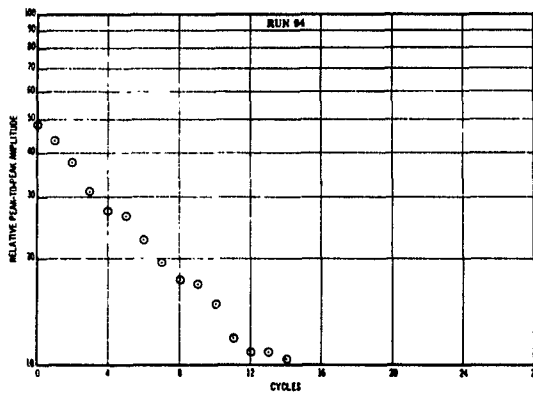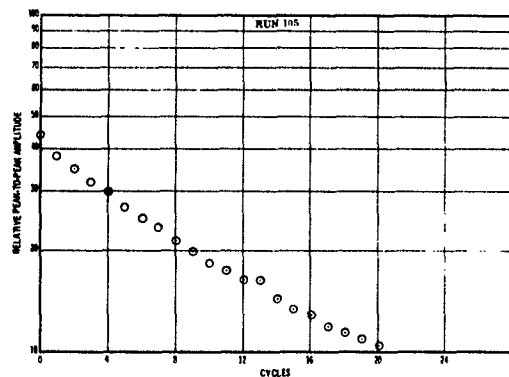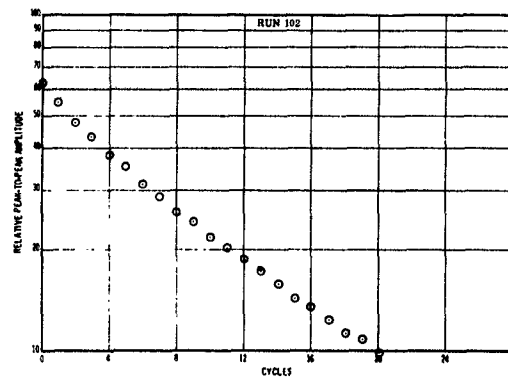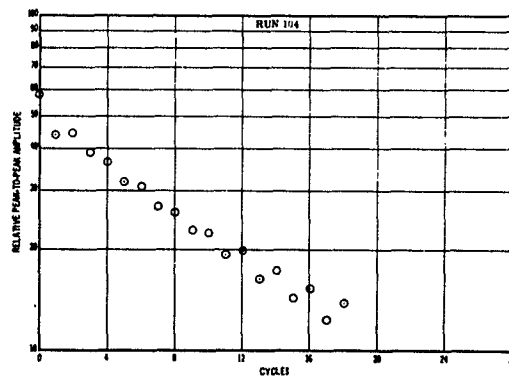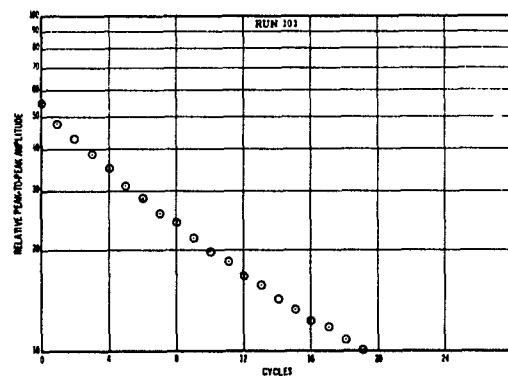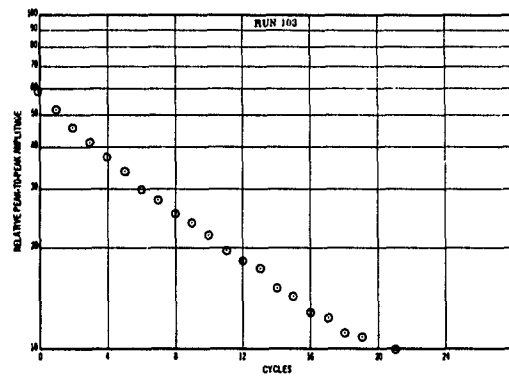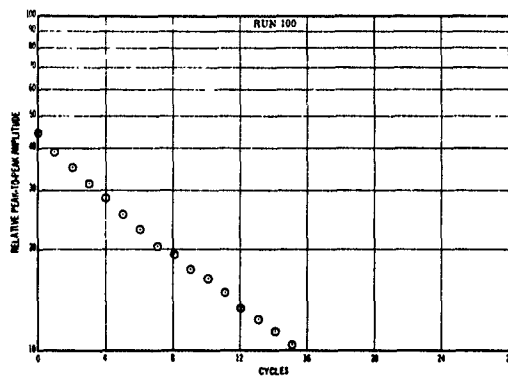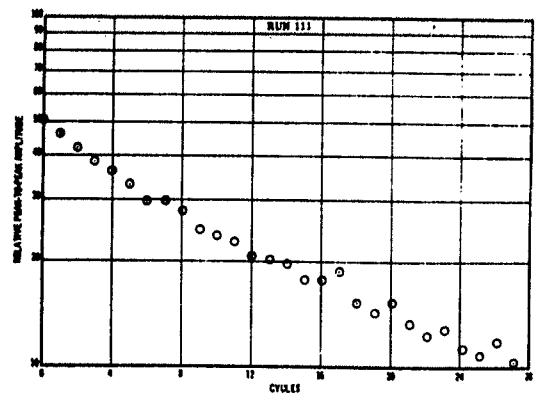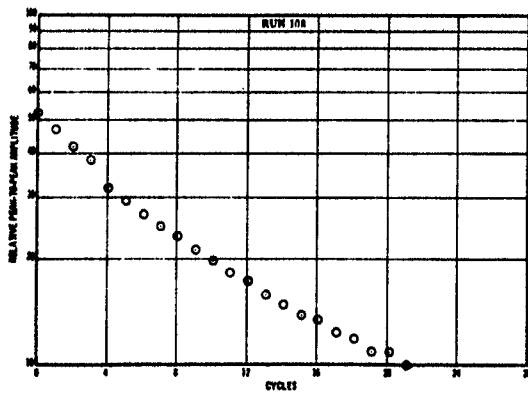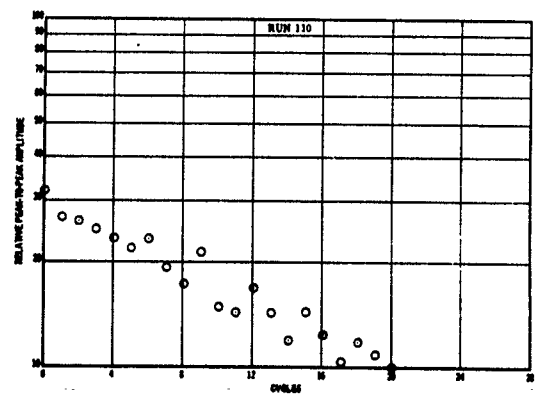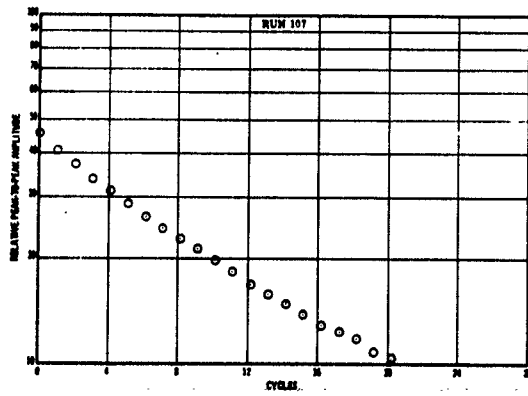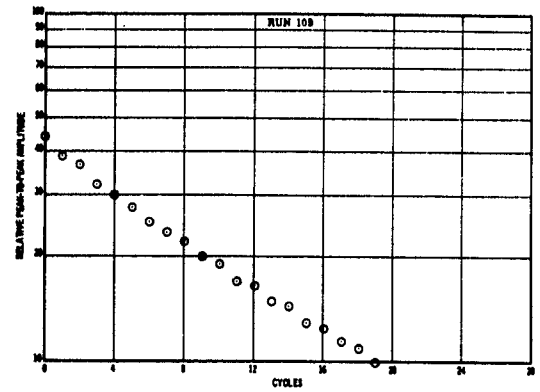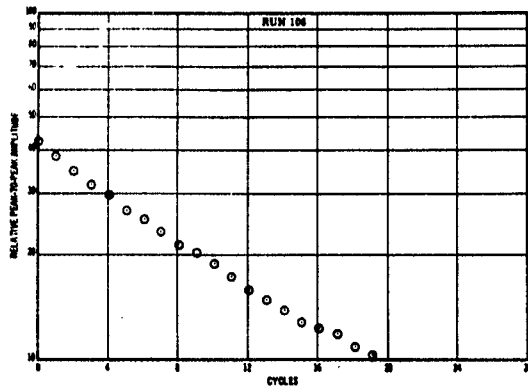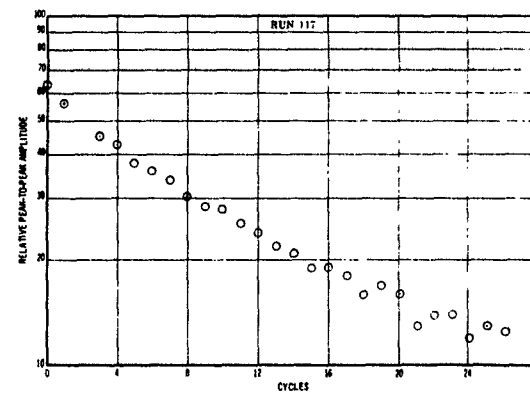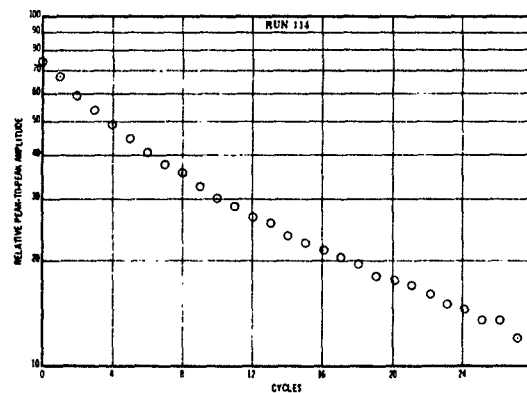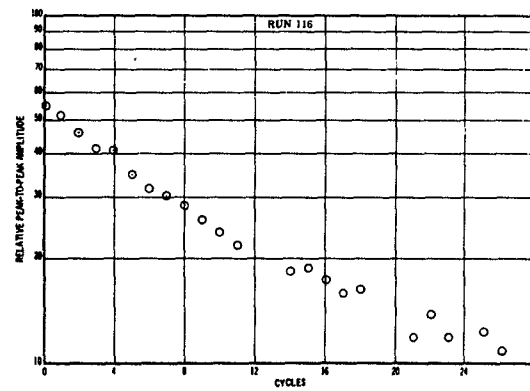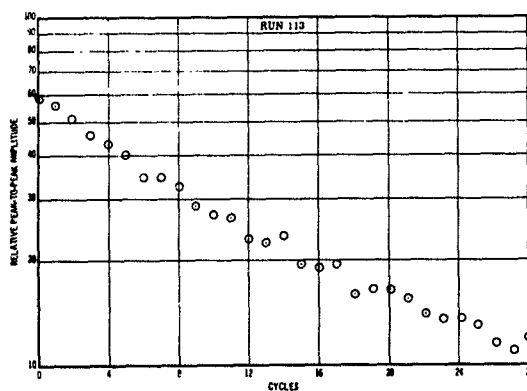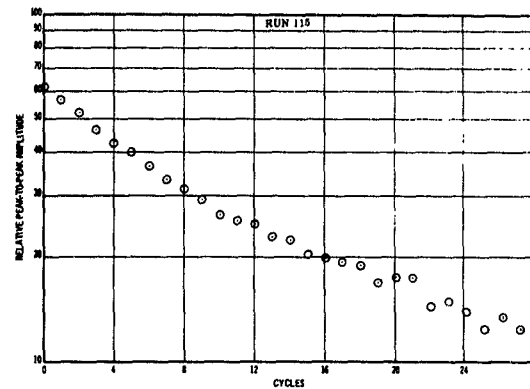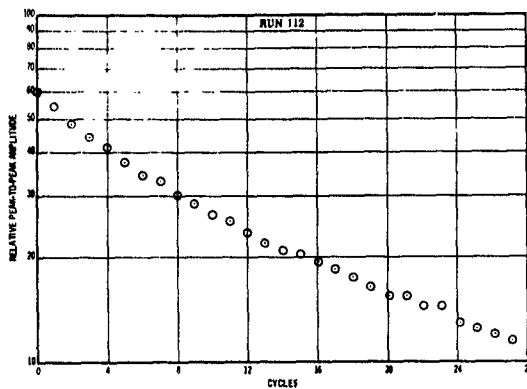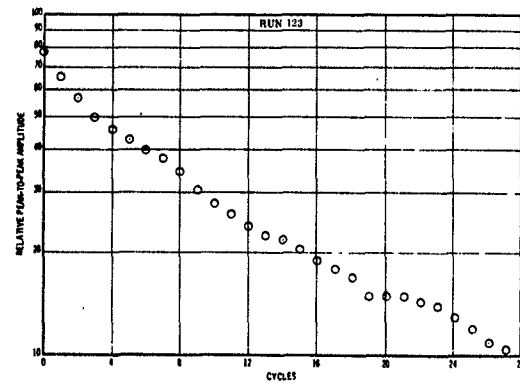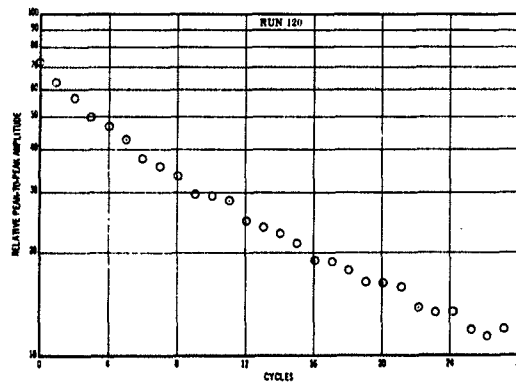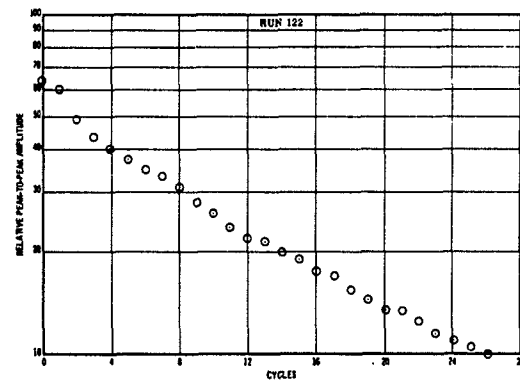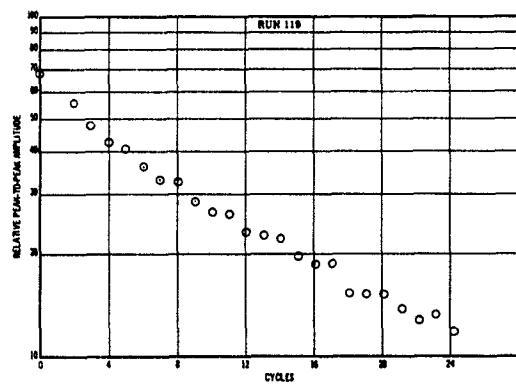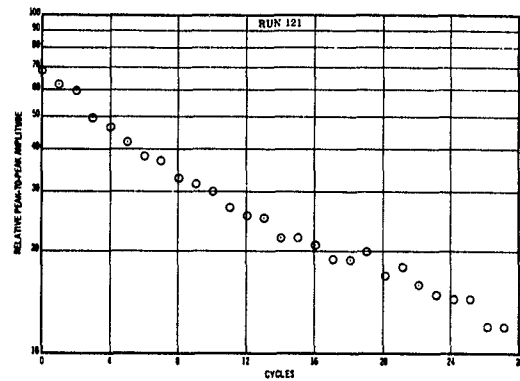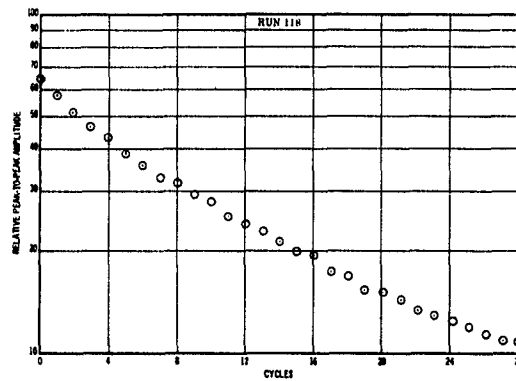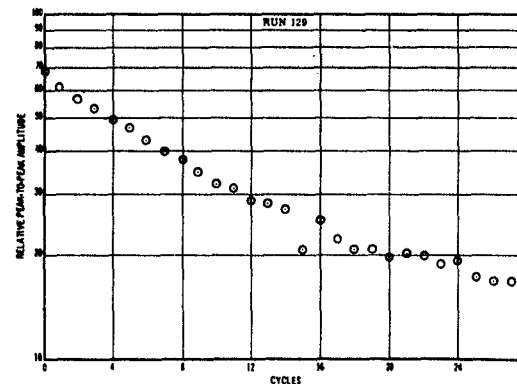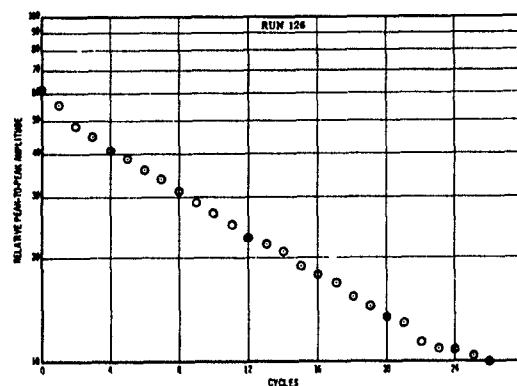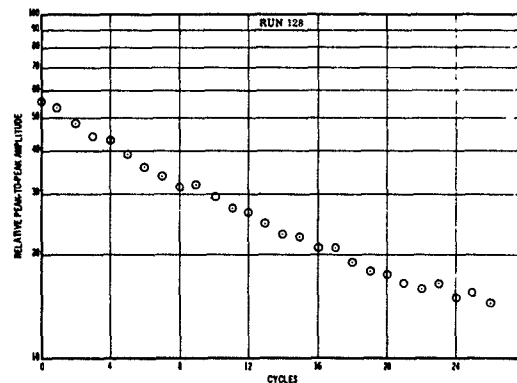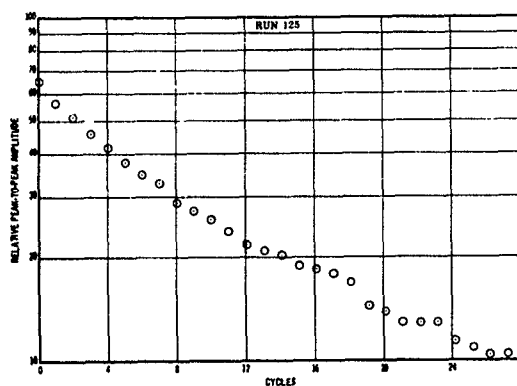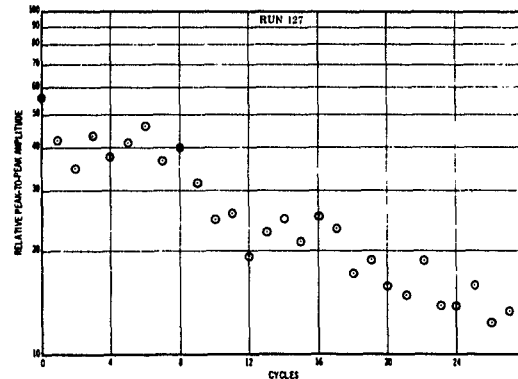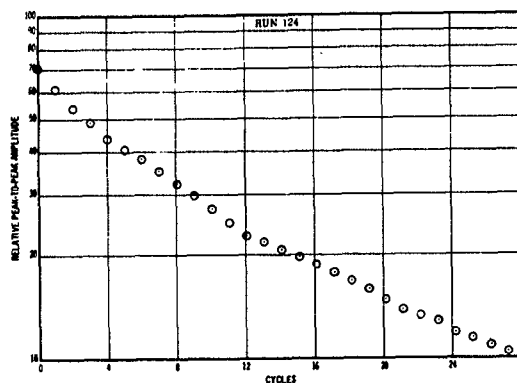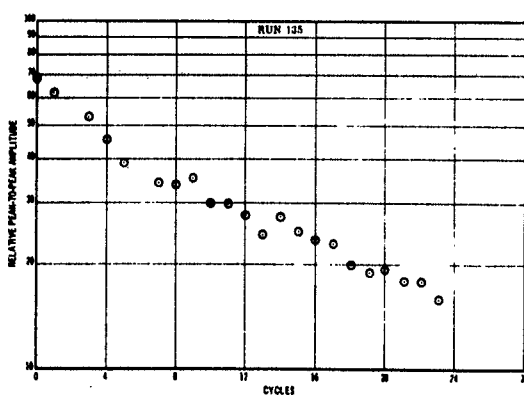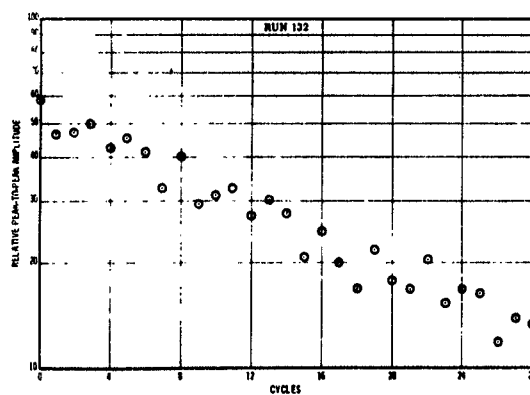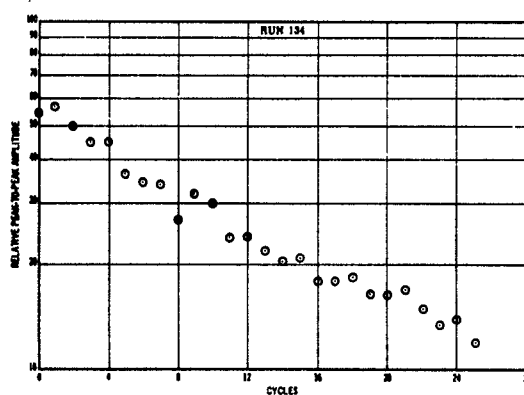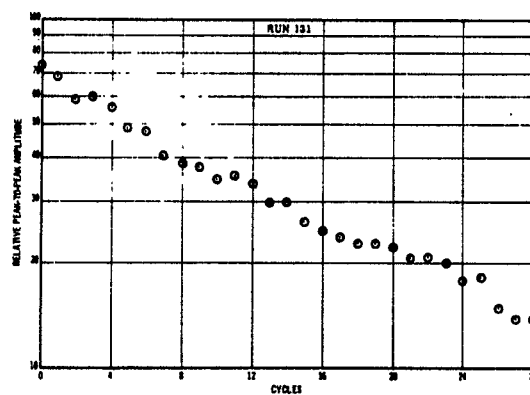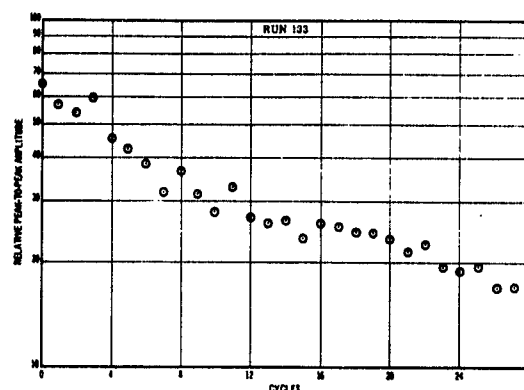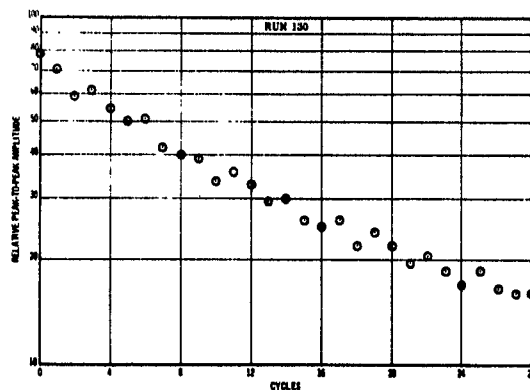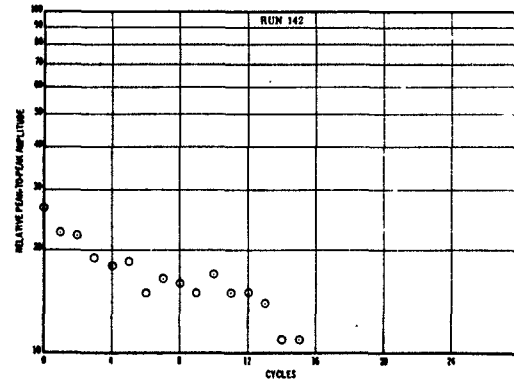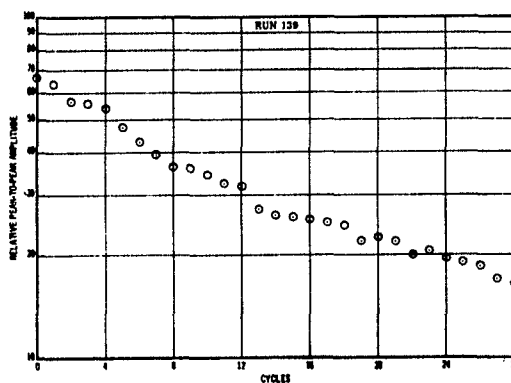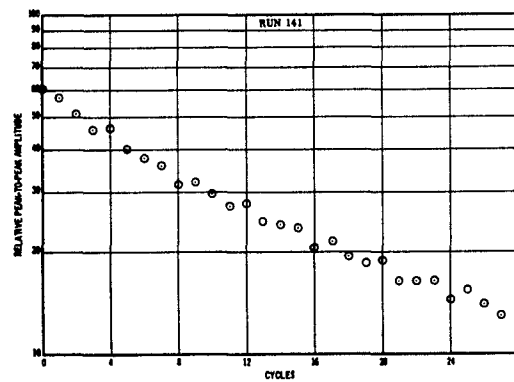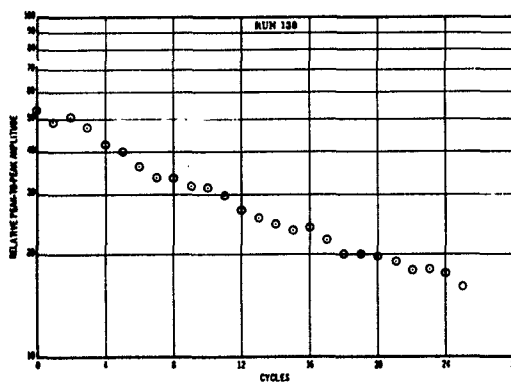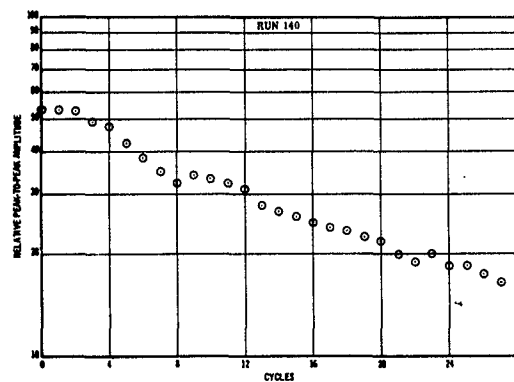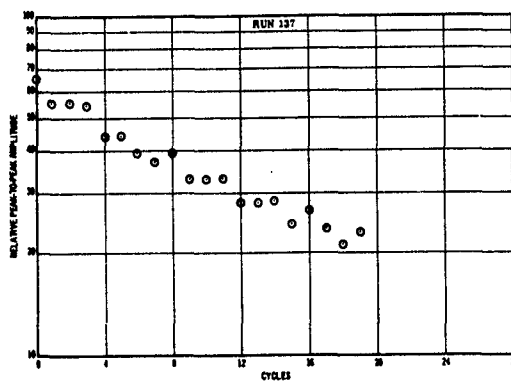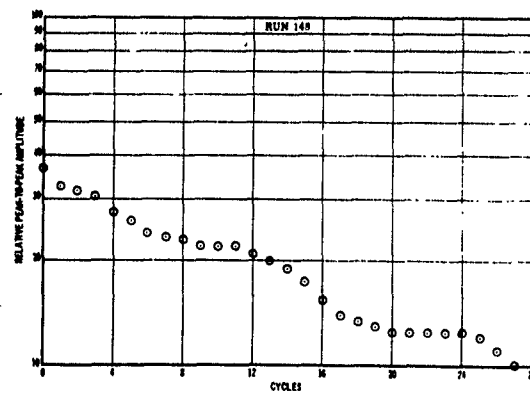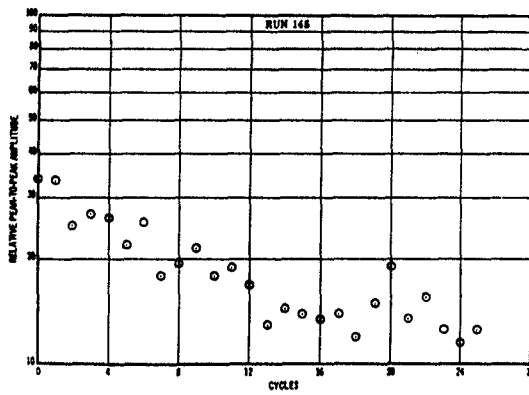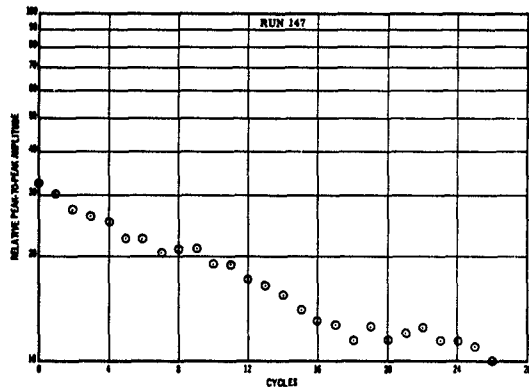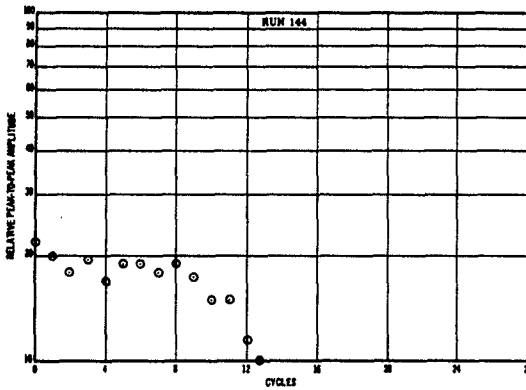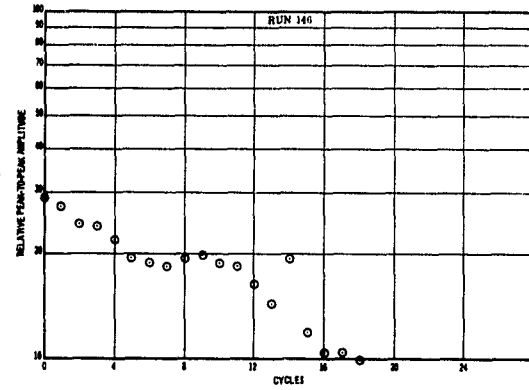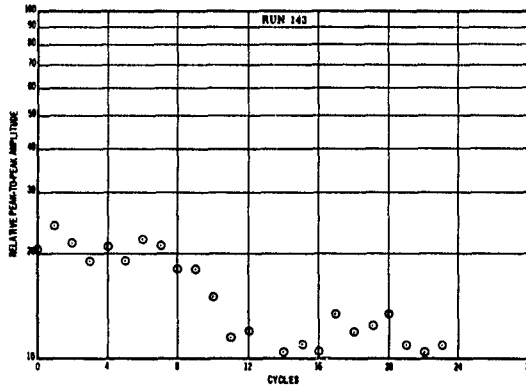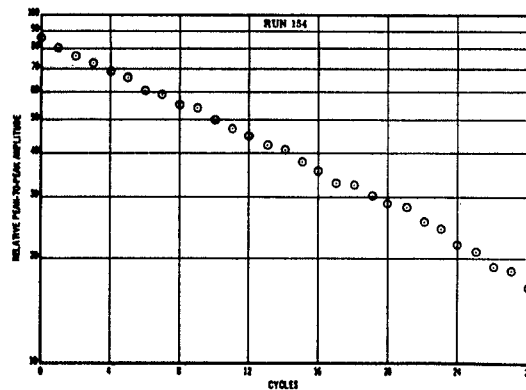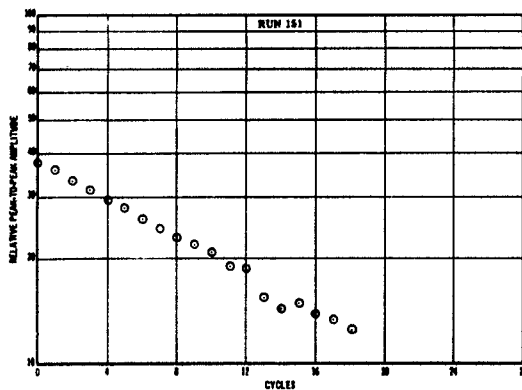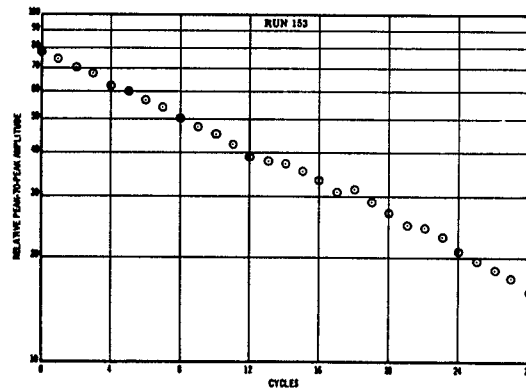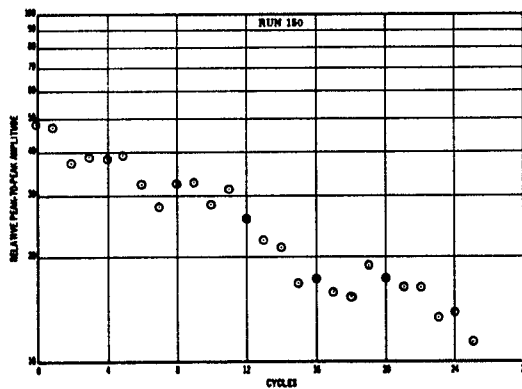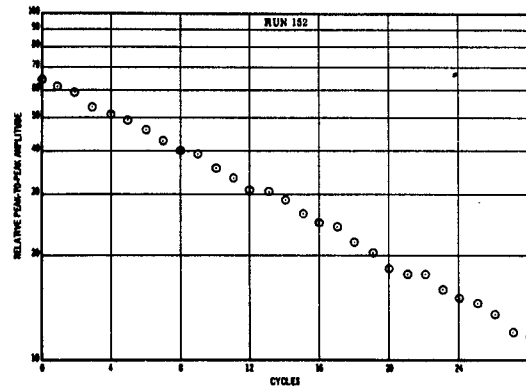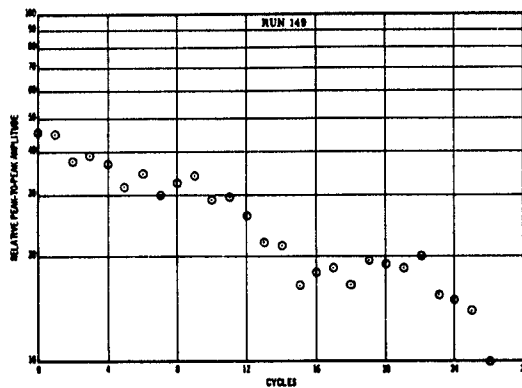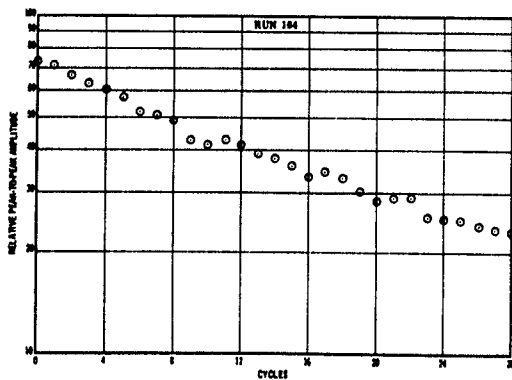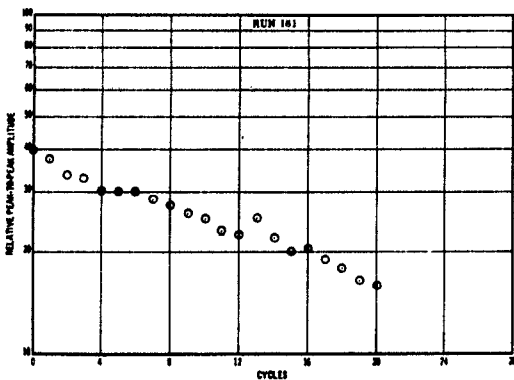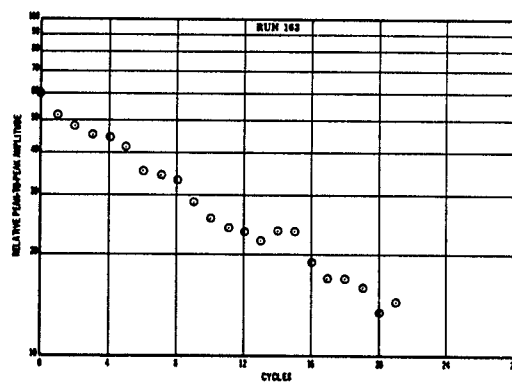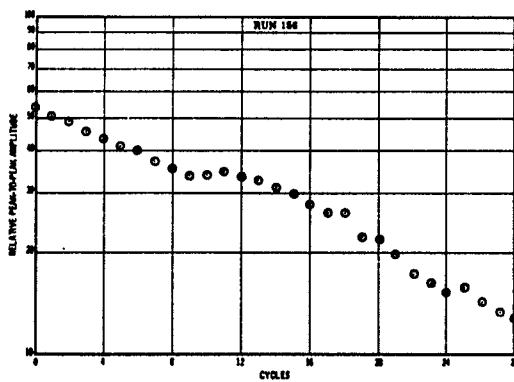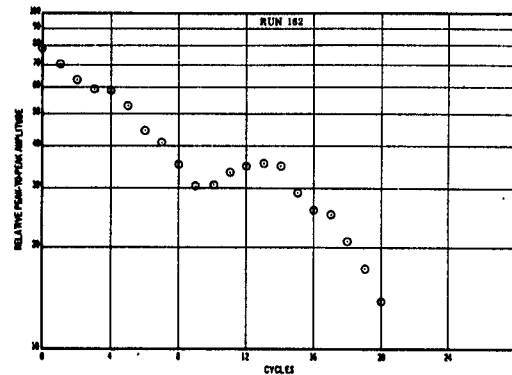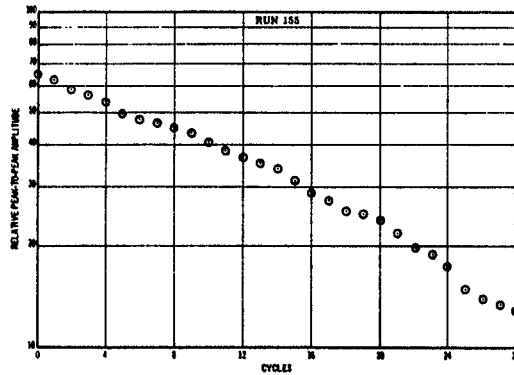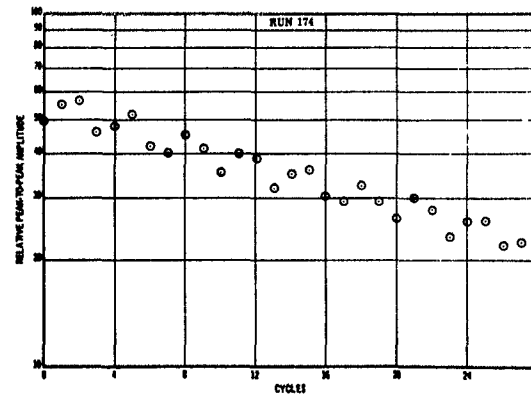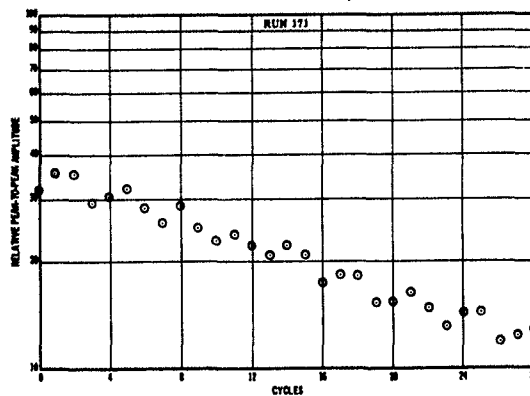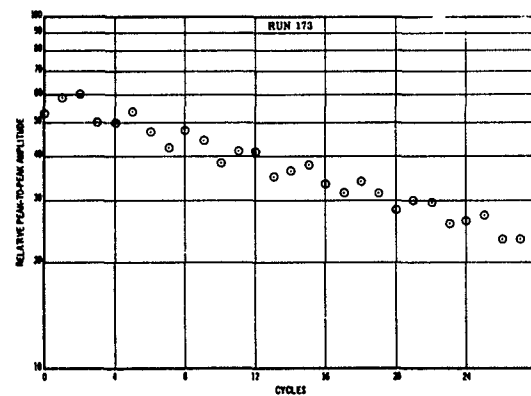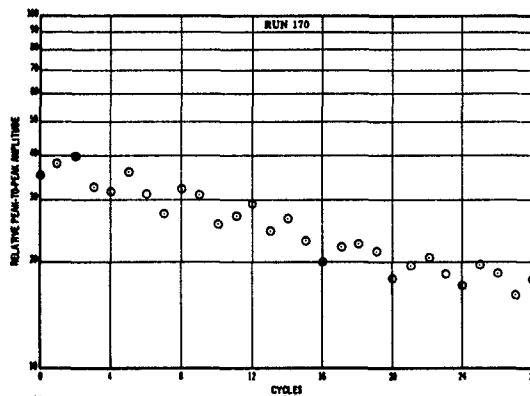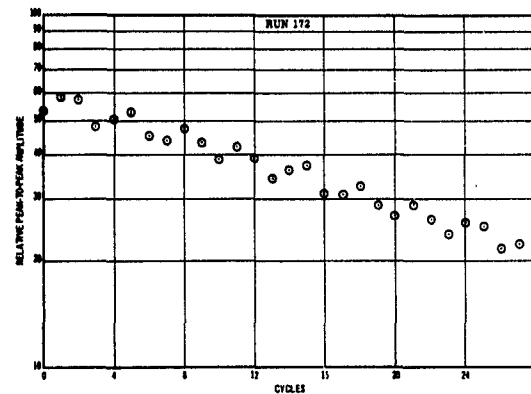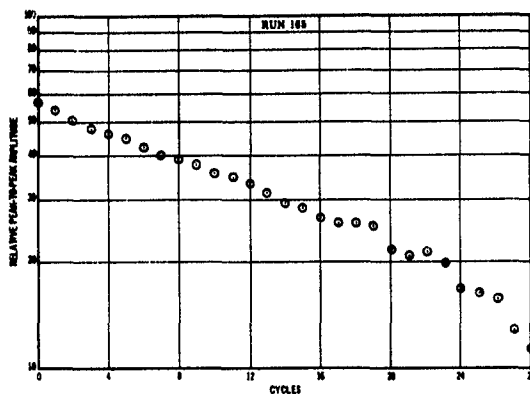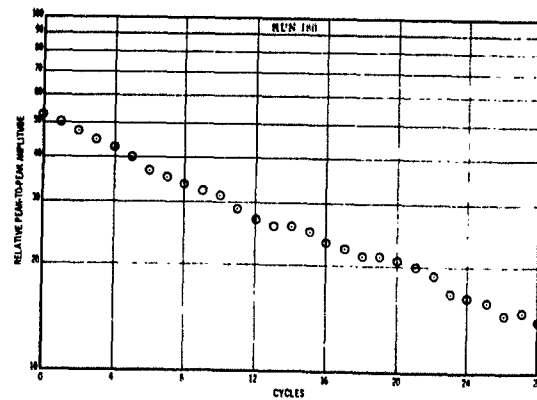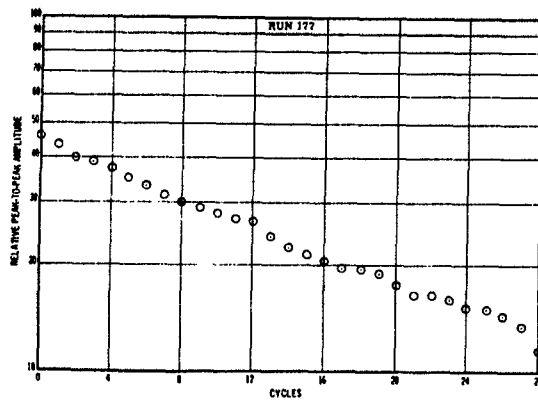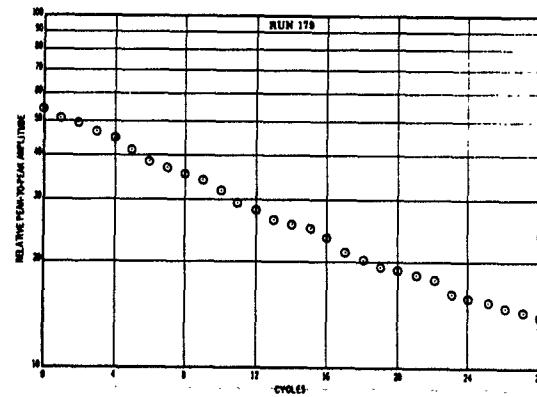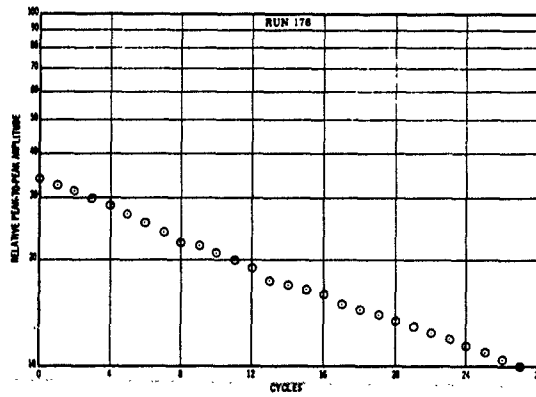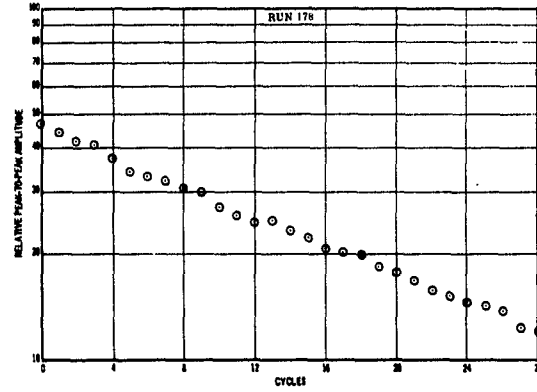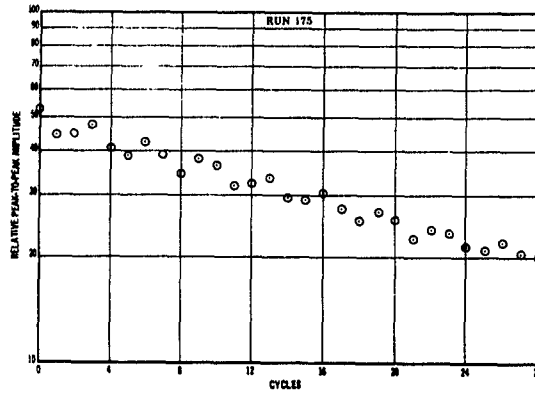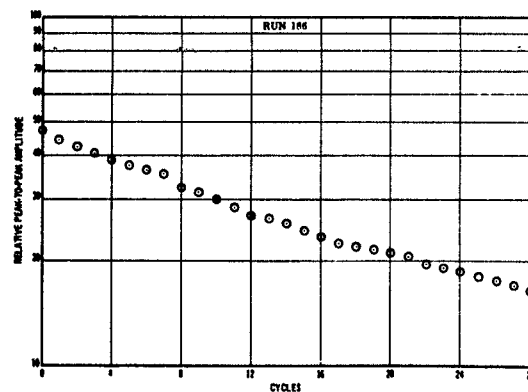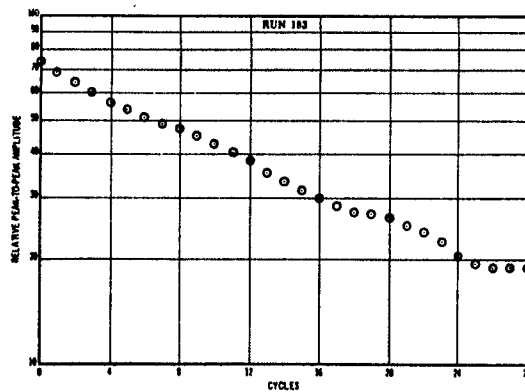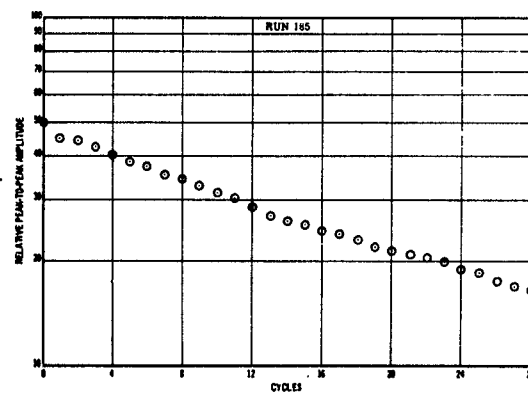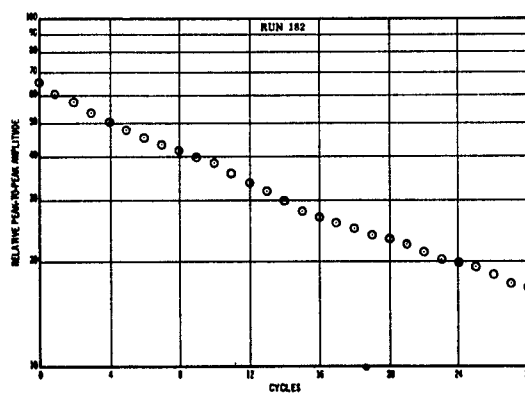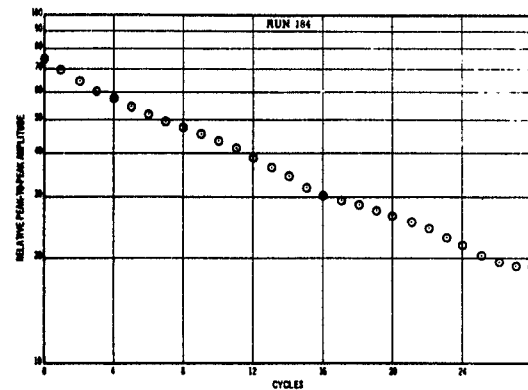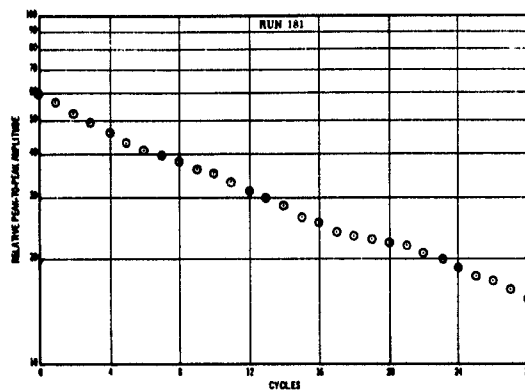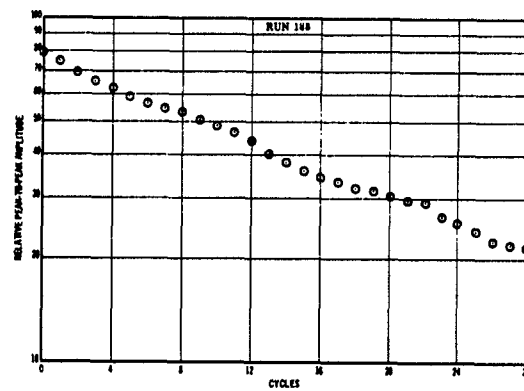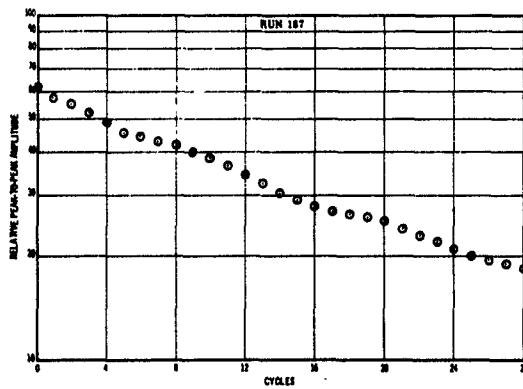
RUN 123

APPENDIX B

SUPERIMPOSED PLOTS INDICATING DAMPING RATIOS

OVERLAY FOR DETERMINING DAMPING RATIOS

COMPOSITE, RUNS 40,43,47,48,49
DAMPING FACTOR APPROX
2.05% OF CRITICAL

COMPOSITE, RUNS 30,31,32,33,34
DAMPING FACTOR APPROX
0.52% OF CRITICAL

COMPOSITE, RUNS 51,53,55,56,58
DAMPING FACTOR APPROX
0.60% OF CRITICAL

COMPOSITE, RUNS 35,36,37,38,39
DAMPING FACTOR APPROX
1.06% OF CRITICAL

COMPOSITE, RUNS 60,61,62
DAMPING FACTOR APPROX
0.57% OF CRITICAL

COMPOSITE, RUNS 68,69,70,72,73
DAMPING FACTOR APPROX
0.90% OF CRITICAL

COMPOSITE, RUNS 94,95,96,97,98
DAMPING FACTOR APPROX
2.14 % OF CRITICAL

COMPOSITE, RUNS 105,106,107,108,109
DAMPING FACTOR APPROX
1.30% OF CRITICAL

COMPOSITE, RUNS 77,78,81,82,93
DAMPING FACTOR APPROX
1.42% OF CRITICAL

COMPOSITE, RUNS 99,100,101,102,103
DAMPING FACTOR APPROX
1.66% OF CRITICAL

COMPOSITE, RUNS 88,89,90,91,92
DAMPING FACTOR APPROX
0.79% OF CRITICAL

COMPOSITE, RUNS 185, 186, 187, 188
DAMPING FACTOR APPROX
0.76% OF CRITICAL

COMPOSITE, RUNS 171, 172, 173, 174, 175
DAMPING FACTOR APPROX
0.63% OF CRITICAL

COMPOSITE, RUNS 181, 182, 183, 184
DAMPING FACTOR APPROX
1.00% OF CRITICAL

COMPOSITE, RUNS 161, 164, 165
DAMPING FACTOR APPROX
0.78% OF CRITICAL

COMPOSITE, RUNS 176, 177, 178, 179, 180
DAMPING FACTOR APPROX
0.88% OF CRITICAL

COMPOSITE, RUNS 111, 112, 113, 114, 115
DAMPING FACTOR APPROX
1.45% OF CRITICAL

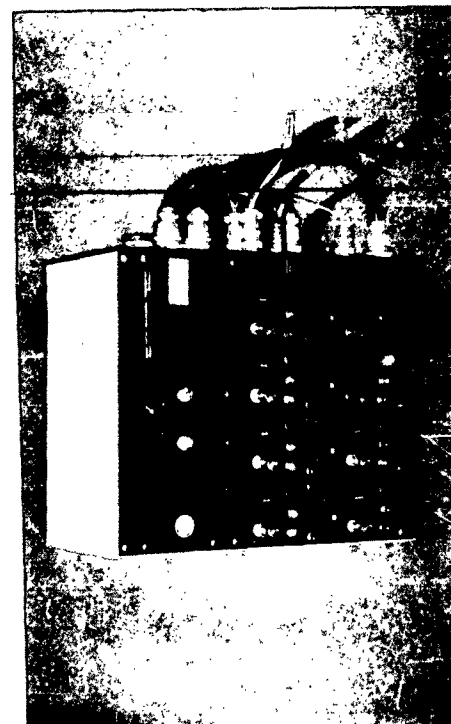APPENDIX C

EQUIPMENT USED IN TESTING
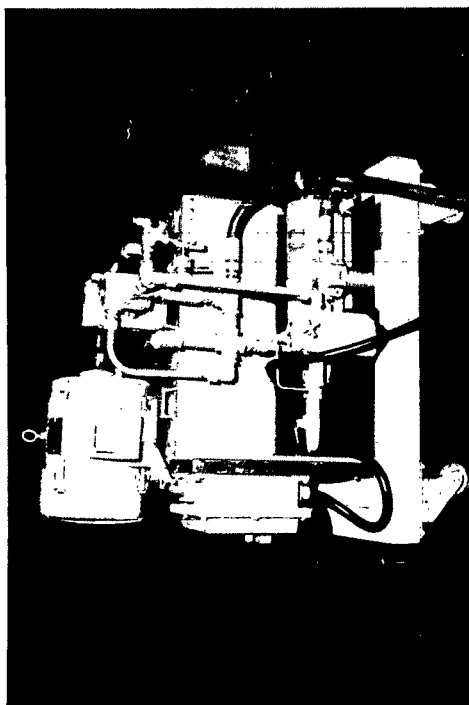
Load Cell Calibration Device

Strain Gage Installation
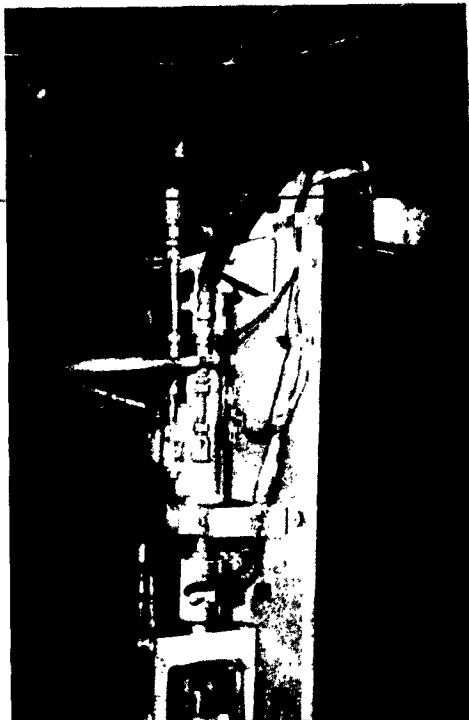
Load Cell Installed in Actuator
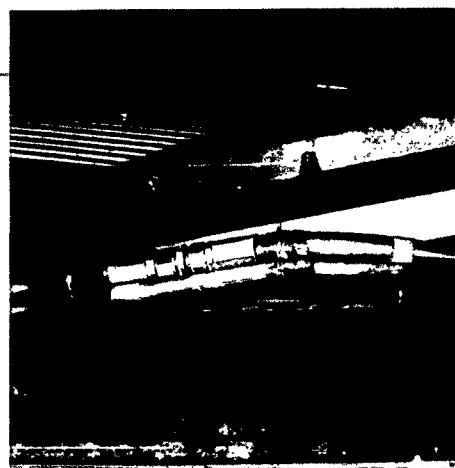

Strain Gage Transducer

Hydraulic Pump

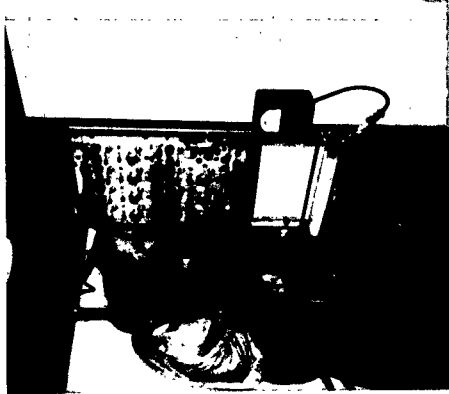Hydraulic Actuator Clamp Mechanism
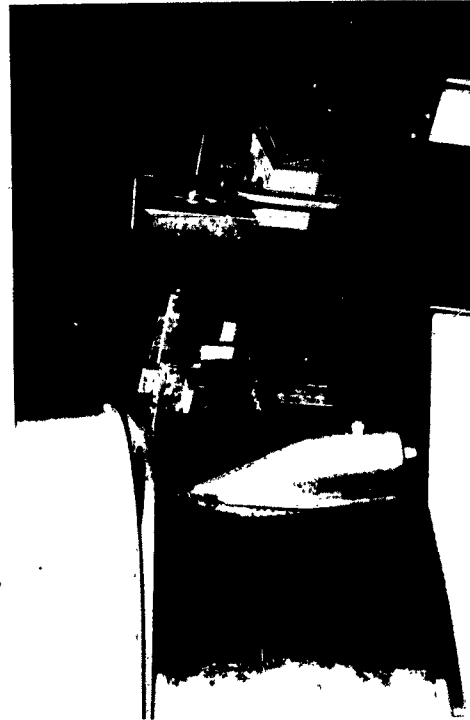and Position Transducer

Agena Umbilicals

Routing of Hydraulic Lines

Layout of Data Recording Equipment
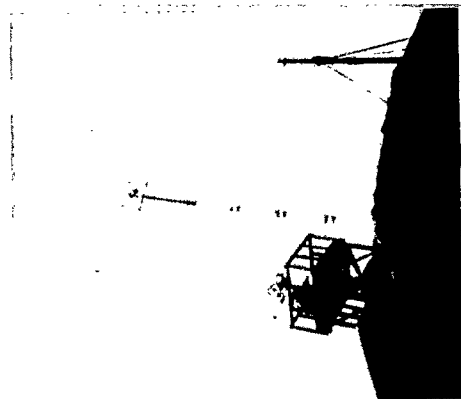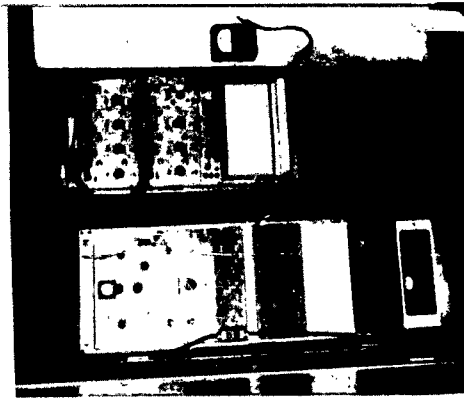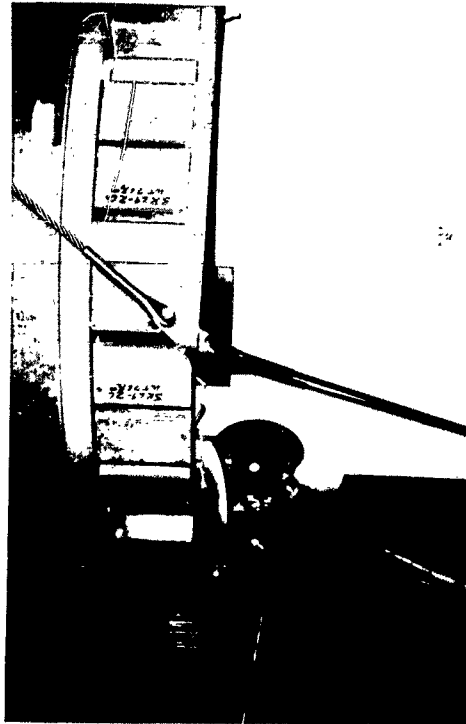

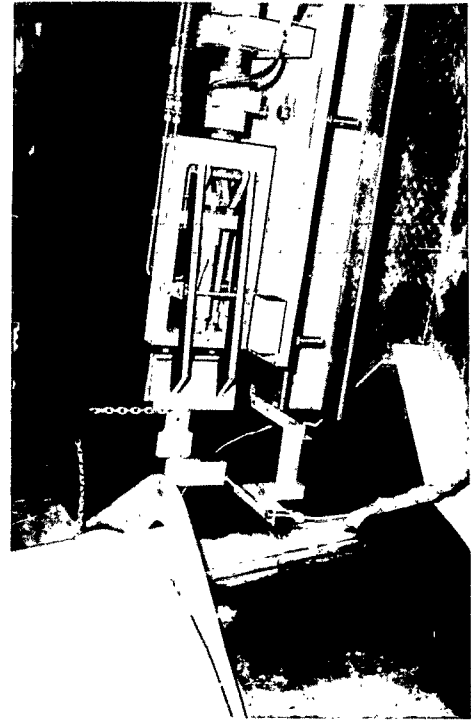Screw Device for Applying Calibrated Loads
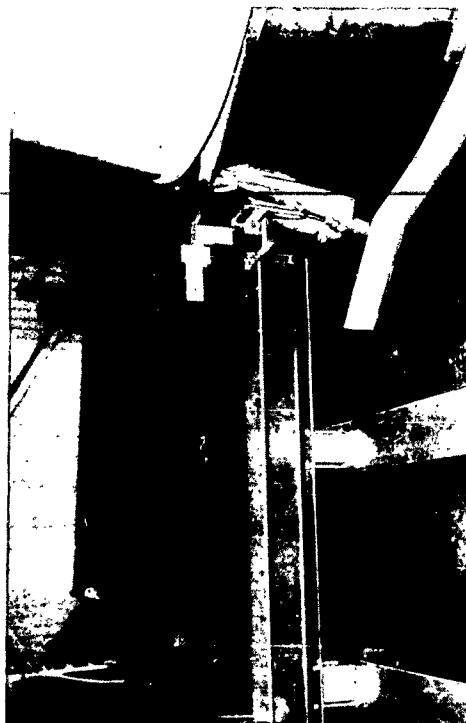

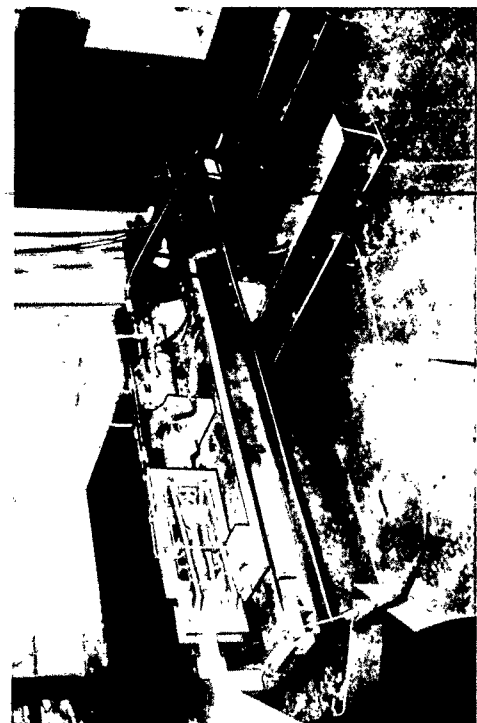Blockhouse Anemometer

Recording Equipment

Agena Handling Ring and Weights

Clamp and Transducer in Operating Position

General View of Yoke and Transducers

Overall View of Actuator and Transducers

APPENDIX D

SAMPLE DATA RUN